US-EPA- USGS

White Paper: Support for and Translating Narrative Hydrologic Criteria

A summary of existing narrative hydrologic criteria; and information for developing, and quantitatively translating, narrative hydrologic criteria.

U.S. EPA and U.S. Geological Survey

9/26/2012

LIST OF ACRONYMS

CWA-	Clean Water Act
E-flows-	Environmental Flows
EPA-	Environmental Protection Agency
ERA-	Ecological Risk Assessment
HGM-	hydro-geomorphic
NPDES-	National Pollution Discharge Elimination System
POTWs-	Publicly owned treatment works
WQS-	Water Quality Standards

GLOSSARY

Environmental Flows: the hydrologic conditions required for the maintenance of an ecosystem

Upstream: Synonymous with catchment

Catchment: sub-units of a watershed

Process domains: areas defined by distinct geomorphic processes. This definition is part of a larger concept described in Montgomery's (1999) Process Domain Concept is a multi-scale hypothesis that describe the influence of geomorphic processes on aquatic ecosystems as an alternative to the River Continuum Concept by Vannote (1980). A multi-scale hypothesis

River Continuum Concept: a concept used in environmental assessment of rivers that classifies and describes lotic systems based on the biological components along a riverine gradient from headwaters to lower reaches (Vannote 1980). Later revisions of the model included consideration of disturbance and irregularities such as flooding events and human alteration.

1 Executive Summary

2 Introduction

Stewardship of water resources in most parts of the world today faces a distinct but universal challenge: meeting the needs of increasing human use while accounting for and preserving the natural variability and ecosystem function to the greatest extent possible (Instream Flow Council, 2004). Changes in land use and water supply, coupled with climate change impacts will continue to stress water resources. Sound and sustainable management of water across the landscape is integral to the health of all waterbodies, and the aquatic life therein.

Hydrologic conditions play a central role in supporting ecological integrity in streams and rivers. Alteration of the natural flow regime (magnitude, timing, duration, frequency, and rate of change; Poff et al., 1997) can affect the physical, chemical, and biological integrity of water bodies. Alteration of this regime can directly impact habitat necessary for the health of aquatic life and it can directly and indirectly impact other water quality parameters that also affect aquatic life (Poff et al. 1997; Bunn and Arthington 2002; Annear et al. 2004; Poff and Zimmerman, 2010). For example, altered flow regimes can directly impact aquatic life habitat (e.g., increased scouring and stream bank erosion) and water quality (e.g., temperature, delivery of sediment, nutrients, metals, and pathogens to streams, lakes, and estuaries). Thus, excessive alteration can impair water body uses such as aquatic life, recreation, and drinking water. Addressing hydrologic conditions in addition to individual pollutants can provide an effective and comprehensive approach to manage and protect water quality, improve effectiveness of aquatic and terrestrial restoration efforts, and provide for maintenance of designated uses and antidegradation requirements.

2.1 Purpose

In response to widespread evidence that excessive hydrologic alteration has negatively affected biological integrity in water bodies throughout the U.S. (reviewed in Bunn and Arthington 2002 and Poff and Zimmerman 2009, Carlisle et al. 2011), EPA is providing the recommended approaches and tools in this document. The purpose of this information is to support states, authorized tribes, and territories (hereinafter, “states”) that wish to adopt and quantitatively translate explicit narrative water quality criteria for hydrologic conditions that address the protection of aquatic life. This information may support development or revision of water policies and plans that are consistent with state water quality standards (WQS) of the Clean Water Act (CWA).This document draws upon the Ecological Risk Assessment framework

(U.S. EPA 1998) and the experience of the states and tribes that have adopted narrative water quality criteria for hydrologic condition to protect aquatic life designated uses in their waters. This document: 1) provides information and tools to help states quantitatively translate such narrative aquatic life criteria (Chapters 3-4), 2) provides language options for developing narrative hydrologic criteria for states interested in adopting such criteria (Appendices B and C), and 3) describes the basis for addressing hydrologic conditions using CWA mechanisms (Appendix A.

States adopt water quality criteria to protect designated uses in their waters (e.g., aquatic life, drinking water, and recreation) and for this purpose may adopt or may have adopted criteria to protect hydrologic condition. Because aquatic life uses are likely the designated uses most vulnerable to changes in hydrologic conditions, this document focuses on aquatic life. However, other designated uses, including recreation and drinking water, may also be sensitive to changes in the hydrologic regime and likewise benefit from hydrologic criteria development. Such hydrologic criteria could be implemented through other CWA programs such as Monitoring and Assessment, NPDES permits, CWA section 401 certifications, and CWA section 404 permits (see Appendix D).

The effectiveness of a narrative criterion will in part depend on the initial establishment of scientifically defensible methods to translate it. The quantitative translation of such narrative criteria requires knowledge of the relationships between altered hydrology and ecology as well as the underlying causes of alteration. EPA's Ecological Risk Assessment ("ERA") framework (U.S. EPA 1998) is useful in identifying and addressing these relationships as discussed in the next chapters (Chapters 3-4).

To complement the ERA Framework (U.S. EPA 1998), this translation draws upon approaches and methods developed in the environmental flows literature. For the purposes of this document, the term "environmental flows" simply relates to the hydrologic condition required for the maintenance of an ecosystem. There are multiple considerations when developing environmental flows ("e-flows"). Annear et al. (2004) have outlined several major considerations that should be addressed including three societal components: legal, institutional, and public involvement. The societal components are important in setting the goals. In the context of WQS, the designated uses are one of these societal values. Annear also states and five ecological components to consider in developing environmental flows to meet those societal goals- hydrology, biology, geomorphology, physical-chemical water quality, and connectivity (for a description of how hydrologic alteration affects these components, see Chapter 3.4).

3 Concepts and Approaches to Quantify Hydrologic Criteria for Aquatic Life

3.1 Eco-risk Framework

Ecological Risk Assessment (ERA) evaluates the potential effects anthropogenic activities have on aquatic life. It is a broad framework that can be applied to a range of environmental problems associated with chemical, physical, and biological stressors. Rather than a traditional focus on assessing effects of simple chemical toxicity on single species, it is evolving towards an approach focused on assessing cumulative impacts of multiple interacting chemical, physical, and biological stressors on populations, communities and ecosystems. The document, Guidelines for Ecological Risk Assessment (U.S. EPA 1998), describes a process for collecting, organizing, and presenting scientific information to make it more useful for decision making.

The ERA framework is useful in considering the risk hydrologic alteration poses to aquatic life. ERA analyzes stressors and resulting ecological effects to help facilitate awareness and aid decision-making to reduce ecological risk. It presumes that a cause and effect relationship exists (hence the term "risk") and that it can be expressed as a stressor-response curve. The ecological risk assessment process consists of three phases: problem formulation, risk analysis, and risk characterization. The problem formulation phase involves development of a conceptual model, identification of assessment endpoints, and development of an analysis plan.

3.2 Generalized Conceptual Model for Hydrologic Alteration

Conceptual models consist of a written description and diagram that illustrate the relationships and pathways between human activities (sources), stressors, and direct and indirect ecological effects on assessment endpoints (U.S. EPA 1998). The conceptual model links exposure characteristics, with the ecological endpoints important for management goals. Under the CWA, these management goals are established by states and tribes as designated uses of waters of the United States (for example, aquatic life support). In deriving aquatic life criteria, EPA is developing acceptable thresholds for stressors that, if not exceeded, will protect designated uses. A state and/or tribe may implement these criteria by adopting them into their respective water quality standards. (See Appendices B, C and D for more information on WQS adoption, narrative language examples, and considerations in other CWA programs.)

The generalized conceptual model (see Figure 1) in this document is a broad, universal framework, of potential pathways, though all of these pathways are not expected in any one region or watershed. The model may be used to help identify and select the most important pathways for analysis, test relationships between assessment endpoints, sources, and stressors, and identify potential data gaps and other sources of uncertainty. The generalized conceptual model (Figure 1) describes how the sources of stress alter the flow regime. The model includes alterations that produce proximate (direct) and indirect effects on water quality and physical habitat that may ultimately affect the biological endpoints (e.g., growth, reproduction, survival, shift in community, etc.). To see an example of this model applied at a regional scale, see

Appendix F. These models can be redrawn on the basis of new information to help define and prioritize subsequent analyses. Analysis plans are then developed to analyze relationships presented in the conceptual model (and existing concerns or risk hypotheses) using available data.

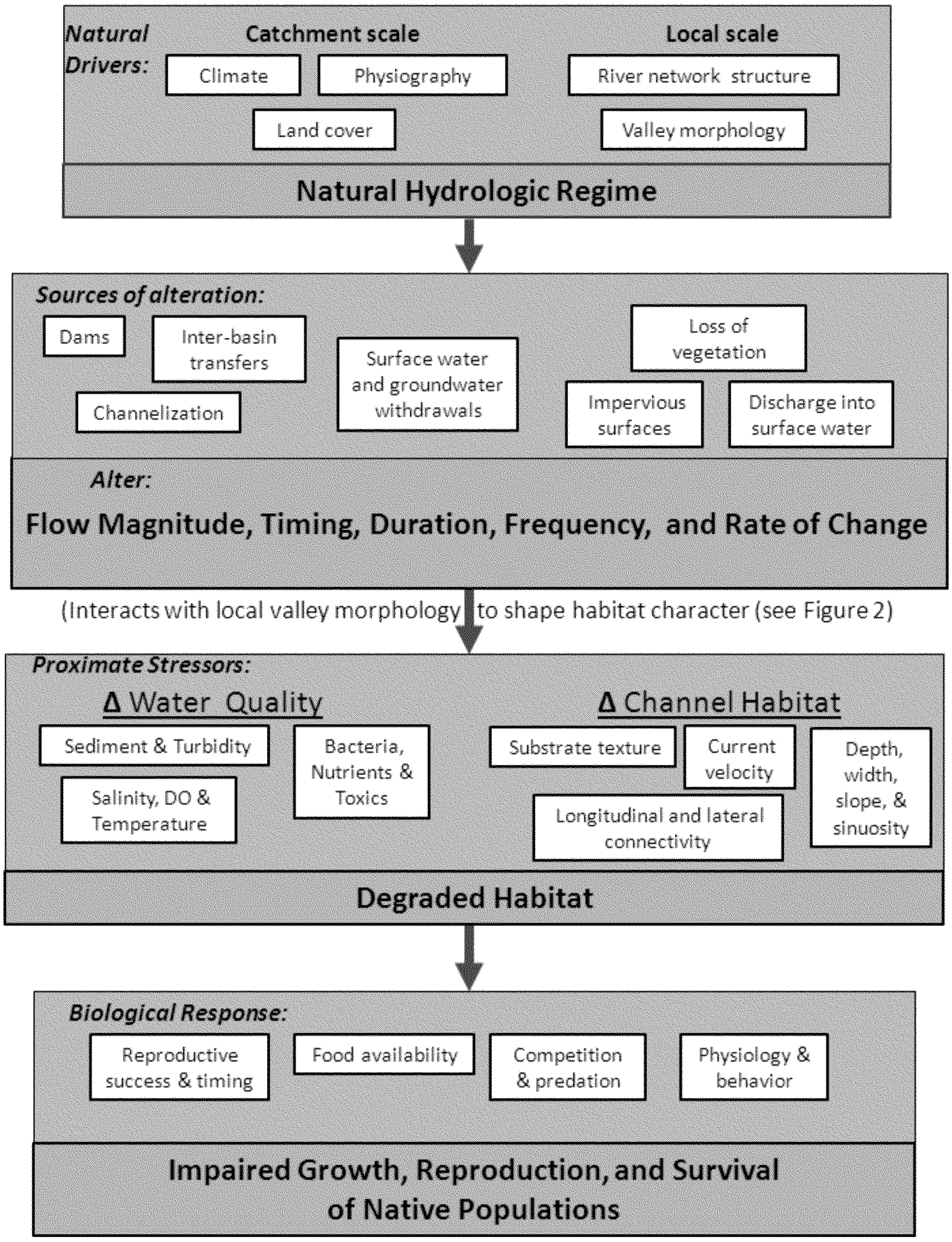


Figure 1: Generalized Conceptual Model for Hydrologic Alteration

3.2.1 The Natural Drivers of Streamflow Regime

It is important to understand the complex natural drivers of stream flow regime, unaltered by human activities. The stream flow regime is driven by the stream's unique position in the landscape, resulting in unique catchment climate and physiography, and unique human modifications. Natural flows, unaltered by human modifications, are driven by regional climatic conditions, including characteristic patterns of precipitation (e.g., summer monsoons, winter rains), magnitude and timing of snowmelt; and ground water contributions to flow. Under natural flow regimes, streams and riparian areas exhibit habitat features that are created and maintained by flow magnitude, and especially, by flow variability (Poff et al., 1997). Variable flows create and maintain features of channel complexity such as point bars, riffle-pool sequences and ratios, sinuosity, the floodplain, bed material and erosion, bank erosion, and suspended and bedded sediment load (Leopold et al., 1964; Richards, 1982; Simon et al., 2004; Florsheim et al., 2008). Flow regimes (i.e., regular patterns of variable flows) drive seasonal patterns, variability, and predictability that shape water chemistry characteristics, physical habitat conditions, and biological communities, and can be used to evaluate relative importance of abiotic and biotic patterns and processes (Poff et al., 1997; Richter et al,. 1998). Over geologic time, the variability behind each system's flow regime synergistically functions to create a unique system in dynamic equilibrium.

Absent of human activities, streams and rivers largely remain in dynamic equilibrium, except when stochastic (random) large-scale natural disturbance events (e.g., volcanoes, hurricanes) occur. And even then, depending upon the scale of geologic time considered, streams and rivers tend to remain at or soon return to a state of balance. However, increasing anthropogenic activities in watersheds can impact this balance, resulting in changes to the template behind the dynamic balance, thereby altering the natural flow regime. This can result in changes to water chemistry, physical habitat and the biological communities, often in ways that negatively impact the natural functioning of a given system and the ecosystem services it provides (Thorp et al. 2010). Such sources of alterations are described in Section 3.3 and depicted in the second box describing alterations in Figure 1. It should be noted that the relative impact of these alterations should be considered in the larger landscape context (see Figures 2 and 3). For example, activities resulting in channelization will have different impacts depending on the physiography, climate regime, and location in a catchment and may also be cumulatively affected by upstream stressors.

3.2.2 Process Scales and the Hydrologic Regime

Effective water management including environmental flows, requires a knowledge of the components and processes and that govern ecosystem functioning. This section describes the connections and controls from a landscape perspective as water moves through a watershed, illustrating the importance of the physiological context of a watershed as a driver of stream flow regime (for both natural drivers and anthropogenic alterations to the flow regime). The controlling processes occur on two spatial scales "catchment" (or "upstream") and "local", and control flow regime and the resulting ecological processes (Figure 2). The term, "catchment" is used for these sub-units of the larger watershed as it is helpful to have a term different from "watershed" ("upstream" and "catchment" are synonymous). ("Catchment" is a standard term used in hydrology and descriptive of "catching" the precipitation inputs.) The local scale is the second scale of flow regime controls and can be thought of as "point modifications" nested within the catchment-influenced hydrology at the larger scale.

River networks are composed of a linear mosaic of hydro-geomorphic (HGM) valley segments (similar Montgomery's (1999) "process domains", or Frissel et al. 1986; Maxwell et al. 1995; and as described in Wang and Seelbach et al. 2006). Each HGM valley segment of interest has a unique upstream catchment or drainage area; the downstream end of the segment aligns with its catchment. **It is critical to remember that each segments' catchment includes those sequentially upstream; that is they are cumulative.**

Catchment area and associated characteristics (e.g., precipitation, evapotranspiration, slope, soil texture, land use, etc.) are the independent variables that drive models of stream flow regimes (Dunne and Leopold 1978). These variables can vary greatly between rivers in the United States (Poff, 1997), among rivers within a state or even for tributaries within a major watershed, and determine the annual water budget for a given stream segment (Wang et al. 2006). 2011 Seelbach state report, YEAR, OTHER REFERENCES, TEXAS, MINNESOTA, VIRGINIA).

Catchment characteristics such as physiography and stream network determine water routing via either overland flow or infiltration resulting in aquifer storage and shallow groundwater pathways. In general, overland flows create flashy flow streams with spates while shallow groundwater pathways usually create stable flow streams with strong summer baseflows that are fed by shallow groundwater (Wiley and Seelbach, 1997; Zorn et al. 2012). Stressors such as land uses can modify the routing of surface water and shallow groundwater. Agricultural and urban land uses modify the natural catchment-level routings of water via surface water or shallow ground water pathways by usually increasing surface water overland flows and decreasing infiltration. This is a systemic, landscape-scale change to the hydrology that is semi-permanent and a major impact on stream flows and ecosystems. The star symbols in Figure 1 indicate the point where a key hydrologic stressor occurs in the conceptual model (which process and which scale).

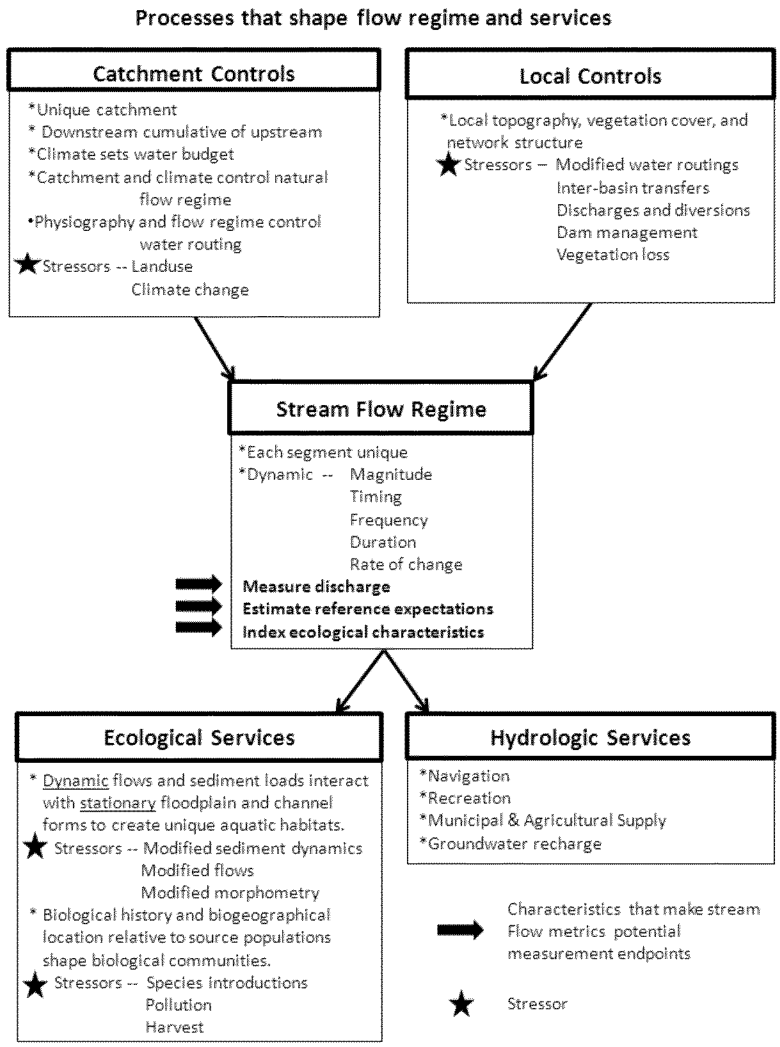


Figure 2. Processes and scales impacting flow regime and resulting ecological characteristics. Stars denote potential stressors that may be present at various process scales. Arrows denote characteristics that may make the component a useful indicator of ecological condition.

The second scale shaping the flow regime is local. “Local Controls”, or local influences and may be “point” modifications to the underlying parent hydrology set by the catchment character. These are often dramatic in impact and affect. They may occur in the immediate segment of interest, but the upstream effects generally accumulate down to the segment of interest as well. Riparian vegetation, local topography, and network structure are highlighted as the “natural” components of the water cycle that occur at this local scale. Evapotranspiration is a very large component of all water budget models, and often the vegetation effect is notable within the riparian zone where water is moving to the stream, close to the soil surface. Local stressors at this scale include modified water routings, e.g., point withdrawals or, point discharges, diversions of surface water or shallow ground water, controlled dam releases, and modified riparian vegetation, to name a few.

Moving to the second tier in the process model (Figure 2), is the flow regime which is shaped by the both local and catchment scale processes. A healthy flow regime supports the stream ecosystem and provides direct benefits to society (see Box 3-1). Physically, it maintains the dynamic hydrology that governs sediment loading and channel geomorphology to create the hydrogeomorphic processes. Together, with catchment characteristics (e.g., slope, geology, soils, climate), the flow regime shapes the aquatic habitat characteristics of each stream segment (see Figure under "Ecological Services") (Montgomery 1999). Aquatic and riparian biological communities are dependent on the stream habitat and thus intrinsically tied to the hydrologic regime because through the physical processes described, the regime shapes the location of source populations (Osborne and Wiley 1992, Angermeier and Winston 1998). Stressors impacting the biology include invasion of nuisance and exotic species, overharvesting, water quality degradation, and geomorphic stressors that modify flow and sediment dynamics. Chapter 3.3 will describe in greater detail sources and effects of many of these stressors.

Box 3-1: Benefits of a Healthy Flow Regime: Hydrologic Services to Society

A healthy flow regime provides direct benefits to society through hydrologic services (a sub-category of ecosystem services). These include improvement of in-stream water supply, water damage mitigation, provision of water related cultural services, provision of water associated supporting services, and improvement of extractive water supply (Brauman et al. 2007). These services can be subdivided into: 1) water for hydropower, recreation, transportation, supply of fish and other freshwater products; 2) reduction of flood damage, dryland salinization, saltwater intrusion, and sedimentation; 3) provision of religious, educational, and tourism values; 4) water and nutrients to support vital estuaries and other habitats, preservation of options and 5) water for municipal, agricultural, commercial, industrial, and thermoelectric power generation uses. (See Figure 1, under "Hydrologic Services".)

Poff et al. (1997) champion stream flow regime as the key intermediate variable in stream ecosystem models. The flow regime integrates the effects of catchment-scale drivers such as catchment climate and physiography, and indexes many stream ecosystem characteristics of interest. The role of the flow regime as a key intermediate variable suggests a wider potential role in the assessment of stream ecosystem health. The primary components of the flow regime (magnitude, frequency, duration, timing, and rate of change) are measurable, can be used in estimating reference expectations, and can be indexed to ecological characteristics. The use of flow metrics as measurement endpoints will be further discussed in Chapter 4.5.

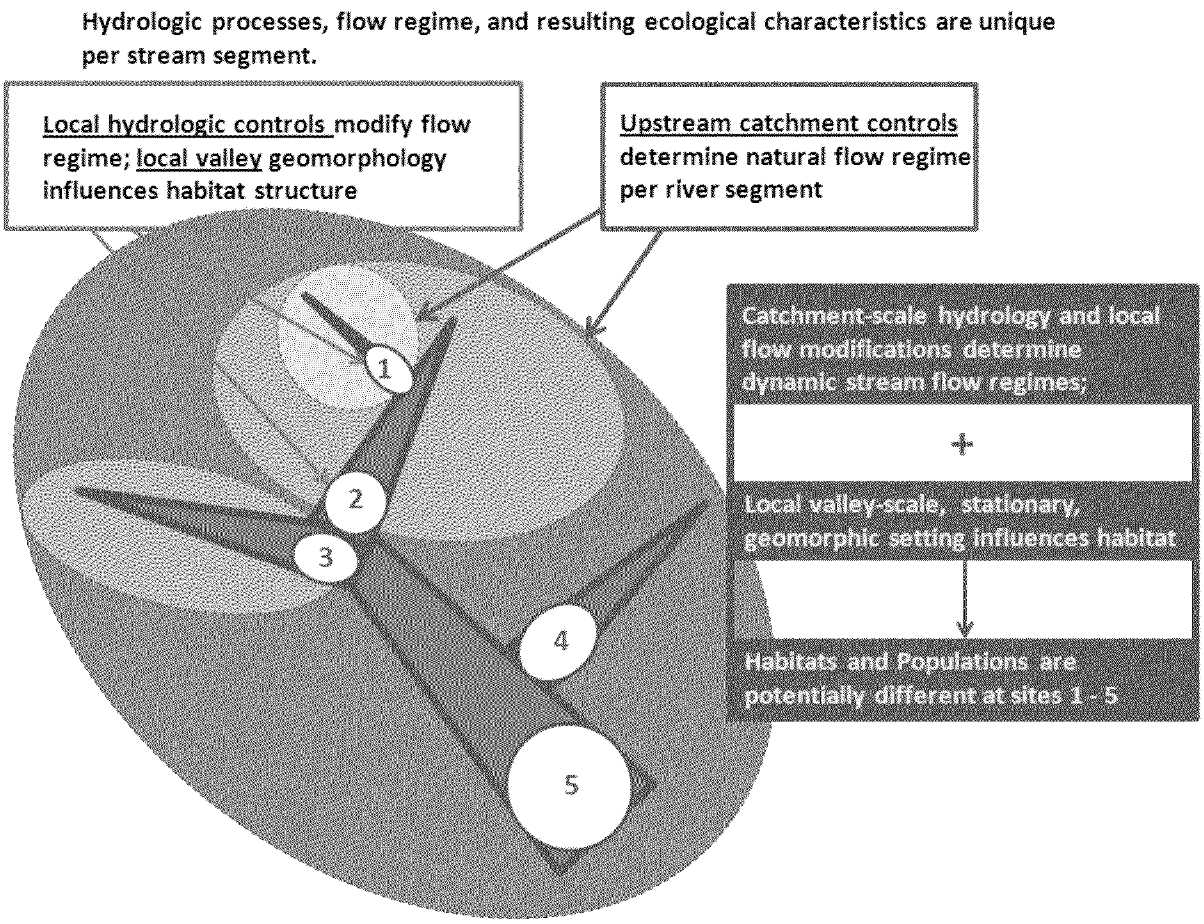


Figure 3. Model of hydrologic process across a landscape.

Figure 3 is a general model of how dynamic hydrologic flows interact with their basins to support and affect ecological communities in various stream sections. It illustrates the principle that flow regime and resulting ecological characteristics are unique by stream segment and an accumulation of those upstream. Each river segment requires a unique application of the process model (Figure 2): hydrodynamic controls, local controls, resulting streamflow regime, and ecological and hydrologic services. Each downstream segment includes cumulative properties of upstream segments, as well as the properties inherent in downstream segments. Appendix C illustrates an application of this organizing principle to the two largest rivers in California, (The Sacramento and the San Joaquin).

3.3 Sources of Hydrologic Alteration

Hydrologic alteration changes the established pattern of hydrologic variation that structured aquatic communities. Several types of human activities or human-made features can significantly alter the natural flow regime (see Figure 1 generalized concept model). While all of these potential sources can alter the natural hydrological regime, and in turn, aquatic communities (i.e., aquatic life uses) they are not all necessarily expected to occur in a given watershed or region, an understanding of the potential sources that are present can provide useful information.

3.3.1 Dams

Dams are designed to control streamflows for various societal purposes. The more than 80,000 dams (Graf 1999) on U.S. waterways (Figure 4) are used to reduce flooding, store water, produce electricity, and maintain navigation. Therefore, dams are a major cause of hydrological modification in streams and rivers. Combined with the recreational opportunities many dams create, the socio-economic benefits of controlling natural streamflows have been significant (Collier et al. 1996, Zimmerman et al. 2009, Wang et al. 2011). At the same time, the effects of dams on the chemical, physical, and biological integrity of streams and rivers have been substantial, albeit only partially assessed (Dynesius and Nilsson 1994, Magilligan and Nislow 2005, Poff et al. 2007).

Dams affect stream and river ecosystems in numerous ways. Many dams literally homogenize natural hydrologic variation by eliminating high flows and, if stored water is released during periods of naturally low flow, artificially augmenting low flows (Magilligan and Nislow 2005). If reservoir releases are primarily governed by hydropower demand, streamflows are typically characterized by unnaturally frequent and abrupt changes in flow (*Reference*). Other effects of dams include changes to water temperature (Cassie 2006, Olden et al. 2010) and sediment budgets (Collier et al. 1996), barriers to migratory aquatic biota (*Reference*), and sources of non-native species introductions (Johnson et al. 2008).

Dams can have a large effect on the lotic fish assemblage both upstream and downstream. Hypolimnetic releases have been associated with reduced abundances of fish immediately downstream of dams whereas dams that release from the top (epilimnetic) have been associated with increased diversity of fish downstream, with a reduction of cold-water species (Haxton and Findlay 2008). Temperature regimes downstream of dams can be highly altered resulting in delayed spawning of some fish species and elimination of temperature-specific fish species (Bunn and Arthington 2002).

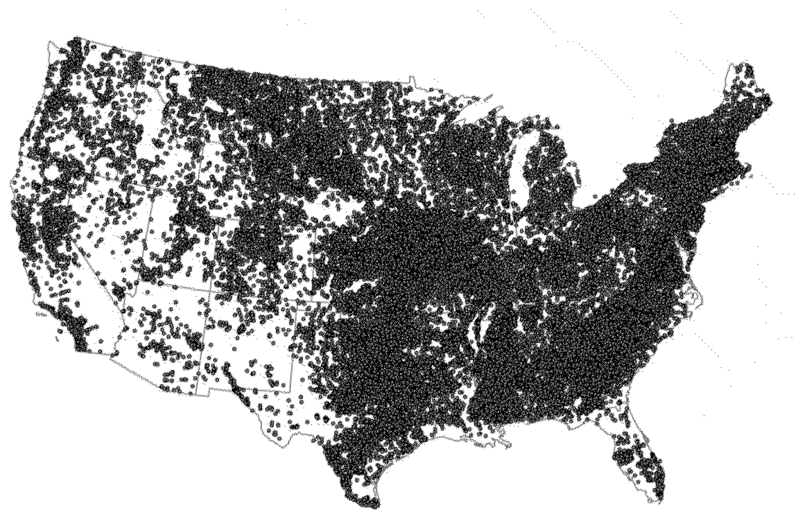


Figure 4. Dams in the conterminous United States from the National Inventory of Dams.

3.3.2 Diversions

In contrast to dams designed to store water, diversion structures are intended to remove specified amounts of flow from the stream channel. Diversion structures range from permanent structures to temporary inflatable dams and water pumps, so it is difficult to quantify how prevalent diversions are. However, according to NHD, permanent infrastructure designed to convey diverted waters, such as pipelines, canals, and ditches, are widespread throughout the United States (Figure 5). Diverted waters are typically used for hydropower, irrigation, municipal, and industrial purposes. Relative to large dams, the effects of small diversions on stream flows is less understood (Bradford and Heinonen 2008) and probably highly variable. The greatest diversions by volume may occur during storm events, but a greater proportion of instream flows may be removed during periods of baseflow (see example in Figure 6).

Interbasin water transfers divert water from one basin to another and are distinct from diversions discussed above as the water in this case leaves the basin and adds to the hydrologic budget of a different basin. In addition to impacts on the water balance, water quality, and ecological processes, these transfers can change the distribution of aquatic organisms and spread pests and diseases (Bunn and Arthington 2002, Davies et al. 2006).

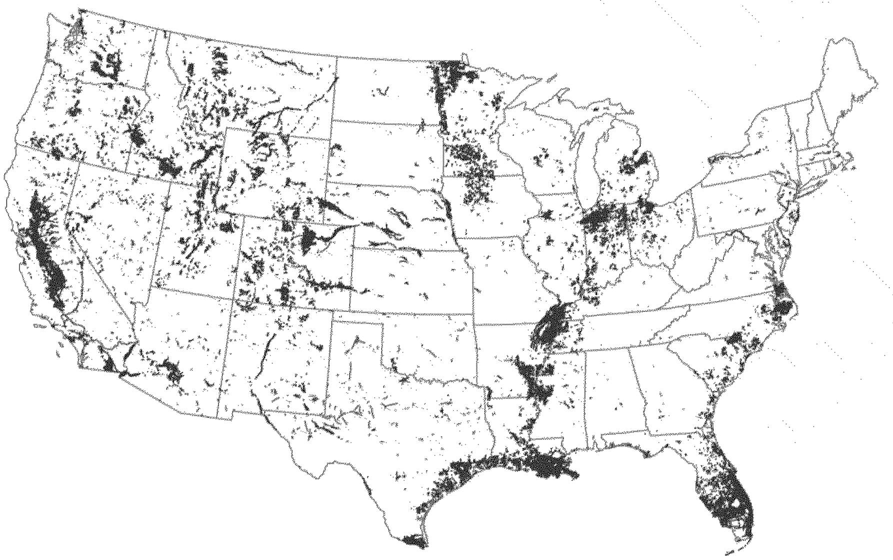


Figure 5. Water conveyance structures (e.g., canals, ditches, and pipelines) in the conterminous United States, from the National Hydrography Dataset.

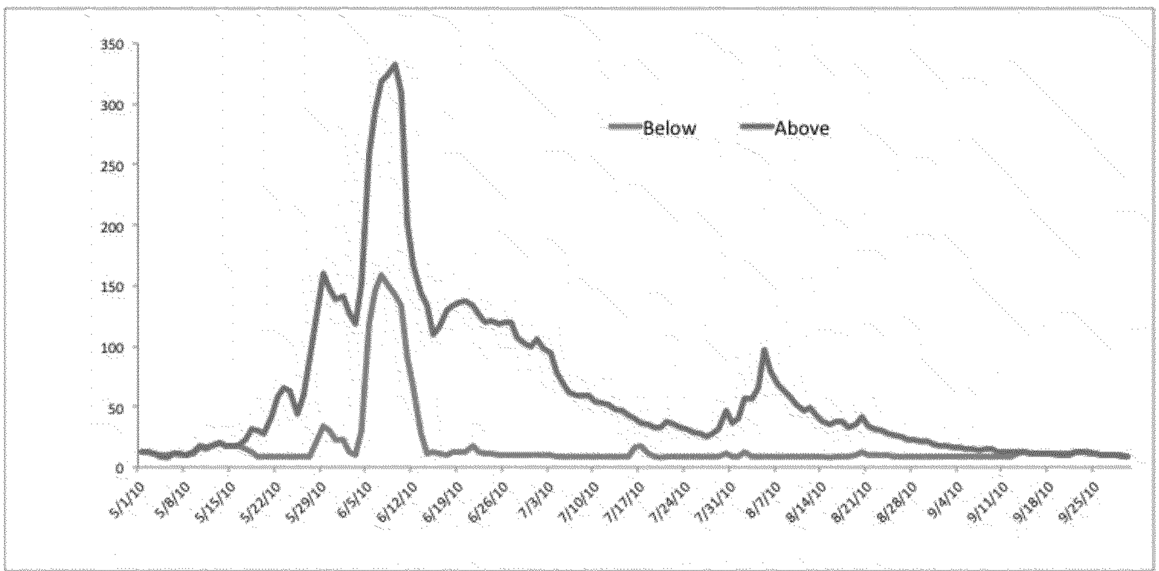


Figure 6. Streamflow diversions from Halfmoon Creek, Colorado, 2010. Stream gages are located above and immediately below the diversion structure. Diverted flows are stored in a nearby reservoir for irrigation purposes.

3.3.3 Groundwater Withdrawal

Shallow groundwater is the primary source of streamflow during periods without substantive precipitation and runoff. Groundwater withdrawals are extensive, occur in many parts of the United States (map?), and have been identified as a cause of reduced streamflows in many systems (Zarriello and Ries 2000, Zorn et al. 2008, Reeves et al. 2009).

3.3.4 Effluents and Other Artificial Inputs

In addition to human activities that *remove* water from streams, some activities *add* water to streams. These augmentations typically lead to unnatural patterns in streamflows. For example, irrigation and Publicly Owned Treatment Works (POTWs) discharges often include water that originated in other river basins. Artificial inputs of flows often shift hydrographs upward by adding some constant amount of flow, but these inputs may be especially noticeable during naturally low flow periods (example in Figure 7). In many arid environments, streamflows during dry seasons are composed almost entirely of effluent from various artificial inputs (Brooks et al. 2006).

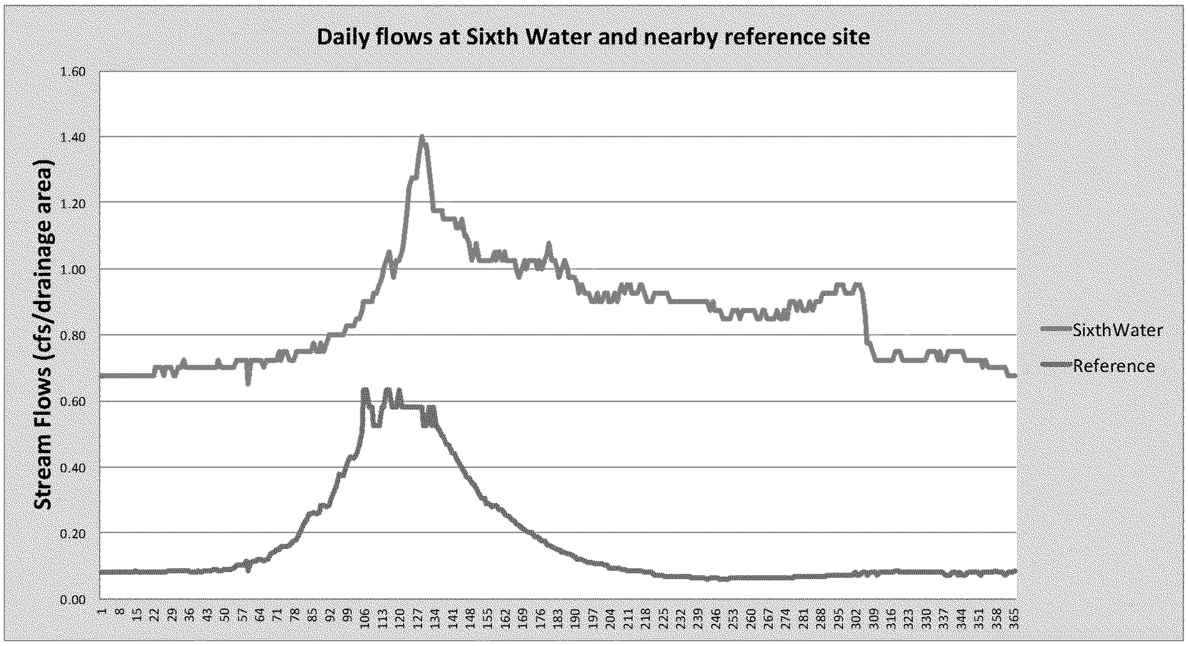


Figure 7. Streamflow is artificially augmented in Sixth Water Creek, Utah

3.3.5 Land-Cover Change and Urbanization

Human land uses can alter streamflow regimes by changing the hydrologic processes that govern the amount and timing of runoff from land surfaces to streams. Hydrologic alteration varies among land uses and streamflow components. Urbanization likely alters natural flow regimes more so than agricultural land uses, but altered flow regime often accompanies the intensification of land use (e.g., the trajectory from natural vegetation cover, to timber harvesting, to agriculture, to urban land use). However, the incremental contribution of each step is not well understood (Armstrong et al. 2011, Wenger et al. 2008, Roy et al. 2005, Roy et al. 2009).

Timber harvesting reduces interception of precipitation and the associated evaporation and sublimation. These changes in combination with decreased transpiration result in greater runoff and base flow (Hewlett and Hibbert 1961; Harr et al. 1982), though the effects can be expected to be transient as a result of reforestation.

Conversion of forests and grasslands to agricultural or urban uses generally involves the construction of engineered drainage systems and a reduction in the storage capacity provided by shallow depressions (wetlands) and soils (Konrad and Booth 2005, Blann et al. 2009). With less storage capacity on the land surface and soil column, a greater fraction of precipitation flows overland and through shallow subsurface paths. Engineered drainage systems and roads networks collect runoff and allow it flow quickly to receiving waters. As a result, streamflow rises rapidly during storm events (storm flow) and reaches higher peak rates in streams with extensive urban land use and in some agricultural areas. Rapid drainage of the land surface causes streamflow to recede rapidly after storm events producing the flashiness characteristic of urban streams. Base flows in agricultural areas typically increase as a result of drainage systems (Blann et al. 2009). Base flow changes in urban areas are more complex. Base flows are generally lower in urban streams in the days or weeks after a storm event than in streams draining natural landscapes, but there may not be much difference in low flow conditions between an urban and natural stream during a prolonged dry period (Konrad and Booth 2005).

Urbanization and agricultural land uses are also accompanied by water management changes that may include inter-basin transfers, increased recharge due to irrigation and on-site wastewater disposal, and groundwater pumping. Each of these activities influences the direction and magnitude of baseflow alteration in urban and agricultural streams. Timber harvesting generally increases total runoff and base flow due to increased snow pack (less interception and sublimation of snowfall) and decreased evapotranspiration.

Hydrologic alteration from human land uses vary seasonally and across ecoregions. The effects on increased stormflow are most evident under dry antecedent conditions (e.g., the beginning of a wet season or storm events during a dry season) when natural landscapes would have had maximum available capacity for storing water. As a general principle, the degree of hydrologic alteration will be related to the change in storage capacity of the land surface and soil column, the reduction in travel time of runoff from the land surface to streams, and storm characteristics (form of precipitation – rain v. snow, intensity, total amount, and frequency). Regions with shallow soils, steep hill slopes, and frequent, intense rain storms would likely show less alteration of natural streamflow regimes from human land use than regions with deep soils and extensive wetlands.

Land use changes and dams have geomorphologic consequences. Land use changes such as increased urbanization or agriculture can result in an alteration of drainage density, which is a measure of stream length per catchment area (km/km^2) (Paul and Meyer, 2001; Dunne and Leopold, 1978; Hirsch et al., 1990; Meyer and Wallace, 2001). This change in drainage density affects flood frequency, flood velocity, sediment supply, bankfull discharge, and recurrence intervals (Wolman, 1967; Leopold, 1973; Dunne and Leopold, 1978; Arnold et al., 1982; Roberts, 1989; Booth and Jackson, 1997).

Altering the sediment supply has dramatic effects on stream morphology and can cause incision or aggradation. Aggradation can increase overbank flooding, increase bank height, and alter width/depth ratios (Wolman, 1967). The resulting channel incision exacerbates width/depth ratios, increases channel migration and bank erosion, and disconnects the channel from the floodplain (Leopold, 1973; Dunne and Leopold, 1978). The geomorphic response will vary longitudinally, with the age of development, slope, geology, sediment characteristics, and land use history (Gregory et al., 1992).

These land use changes degrade aquatic, riparian, and wetland habitat, change flood frequency and intensity, change baseflows, and generally decrease biodiversity. Severing linkages between the channel and floodplain can cause nutrient reductions in the floodplain, desiccate seeds and reduce dispersal, reduce scoured riparian habitat patches for colonizing species, allow for encroachment of vegetation into channels, and eliminate fish access to nursery habitat (Poff 1997; Beechie et al. 2010).

3.4 Effects of hydrologic alteration

3.4.1 Effects on components of the natural flow regime

Alteration of any of the five hydrologic components of the natural flow regime, magnitude, frequency, duration, timing, and rate of change can have drastic effects on the ecological integrity of waterbodies, altering both community assemblages and ecosystem functions (Poff et al. 1997). In the case of magnitude, the reduction or loss of high flushing flows, or a change in seasonal peak flows, can result in:

- declines in abundances of species with life stages that are sensitive to sedimentation;
- disruption of cues for fish spawning, egg hatching, and fish migration; and
- modification of aquatic food web structures, habitat access and maintenance, and nutrient and sediment transport (Poff et al. 1997).

Carlisle et al. (2011) assembled gauged flow data from across the U.S. during the period 1980 – 2007, documenting the alteration of 86% of assessed streams mean minimum and maximum streamflow magnitudes. Diminished flow magnitudes were the primary predictors of observed effects on biological integrity of fish and macroinvertebrate communities (Carlisle et al.2011).

Frequencies of both high and low flows are important for channel formation such as formation of bars, siltation rates, bank erosion, and channel widening, all of which affect numerous ecological properties such as available spawning and nursery habitat and recruitment opportunities for riparian species. Poff and Zimmerman (2009) noted that macroinvertebrates and fish are negatively affected by decreases in frequency of floods or peak flows. A decrease in flood peaks generally resulted in decreases in riparian species abundance and diversity, increased riparian encroachment in the channel, and increased non-riparian species diversity due to reduced or eliminated overbank flooding. For example, riparian species such as cottonwoods and willow are often extirpated when high flows are reduced because they depend on particular rates of groundwater recession after floodplain inundation for seedling growth (Poff et al. 1997).

Duration of particular flow events also affect both instream and riparian habitats and species (Poff and Zimmerman 2009) and can affect abundance and diversity of riparian vegetation, macroinvertebrates, and fish (Poff et al. 1997). Prolonged duration of peak flows or low flows can alter habitat, channel incision, egg and seed dispersal, sediment and nutrient transport rates, and riparian plant cover and diversity. Extreme rates of change can cause high mortality of aquatic species from physical stress and stranding due to rapid dewatering. Ecosystem functions of shoreline and backwater areas can also be impaired by rapid rates of change of flow (Poff et al. 1997).

Altered flow characteristics as described above can affect several riverine ecological processes including geomorphology, connectivity, water quality, and biology (Annear et al. 2004). These direct effects of altered flow regime are described in the next sections.

3.4.2 Effects on Geomorphology

The types of hydrologic alteration noted above can alter fine sediment deposition rates, channel stabilization, point bar, secondary channel, and oxbow development, and can cause erosion and armoring of downstream reaches resulting in changes in habitats. These alterations in habitat types result in changes in the aquatic and riparian biological communities (Poff 1997; Beechie et al. 2010).

3.4.3 Effects on Connectivity

Longitudinal connectivity is disrupted by dams, weirs, and other human-made structures. In the United States every large river and river basin has been altered by these types of intrusions. The maintenance of many aquatic species populations depends on their ability to move freely through the stream and/or river network (Bunn and Arthington 2002). Blocking of longitudinal passage often results in the disappearance or decline of migratory species such as American eel (*Anguilla rostrata*), sturgeon (*Acipenser, Huso, Scaphirhynchus and Pseudoscaphirhynchus* spp.), shad (*Alosa* spp.), salmon (*Oncorhynchus* spp.), shrimp (*Macrobrachium* spp.), upstream of these barriers. The disappearances of these migratory species can result in significantly reduced species richness and reduced commercial and recreational fisheries stocks. They may also influence ecosystem level processes, such as aquatic and terrestrial nutrient cycling, primary production, organic matter processing, sedimentation and the composition of benthic algal and invertebrate communities (Bunn and Arthington 2002, Gende et al. 2002).

Flow alteration by dams and associated structures, channelization, and levees that cause an increase or decrease in flow magnitude can result in reduced lateral connectivity in floodplains, rivers and shallow groundwater interactions, altering floodplain habitats and reducing biological diversity and ecological integrity of floodplains. Hydrologic connectivity of the river channel, floodplain, and groundwater influences the spatial and temporal heterogeneity of floodplain habitats which leads to their high biological diversity (Bunn and Arthington 2002). Important spawning, nursery, and foraging areas for many aquatic organisms are created by the lateral expansion of floodplain habitats during overbank flooding. However, increased flow magnitudes can cause entrenchment and prevent lateral expansion into the floodplain. Decreased flood peaks can reduce the frequency, extent, and duration of floodplain inundation, modifying channel migration and lowering habitat diversity on the floodplain. Decreased lateral connectivity affects recruitment of fish that use inundated floodplains for breeding and juvenile habitat which reduces native species abundance (Bunn and Arthington 2002).

3.4.4 Effects on Water Quality

Altered flow regimes affect the fate and transport of chemicals and can change the physical and chemical properties under which natural aquatic communities have evolved. Specific water quality alterations include temperature, dissolved oxygen, specific conductance, and nutrients, all of which are critical factors affecting species' growth, survival, reproduction, distribution, and abundance.

Stream temperature is tightly linked to streamflow. Temperature regimes below dams tend to be highly modified, with diel and seasonal fluctuations greatly reduced, and the timing of high and low seasonal temperatures shifted by a month or more when compared to upstream temperatures (Pozo et al., 1997; Walker, 1985; Crisp, 1977; Bolke and Waddell, 1975; Hannan and Young, 1974). Stormwater runoff from urban catchments can also affect river and stream water temperatures. Helms et al (2009) found positive correlations for higher stream temperatures, up to 6.6 C in an hour (Lieb and Carline 2000) with increased watershed impervious surface.

Dissolved oxygen concentrations can vary with hydrologic alteration due to its relationship with water temperature and primary production, which can also be influenced by flow (Vliet and Zwolsman, 2008, Zwolsman et al., 2007). Turbulent flows downstream of dams are often supersaturated with gases that are harmful to fish (Baxter, 1977; Fowler, 1978).

Supersaturation of gases can result in mortalities of juvenile and adult fish and have adverse impacts on human health and other aquatic biological communities (Ebel 1970; Walker, 1985; Hannan and Young, 1974).

Specific conductance, a measure of the ability of water to conduct an electrical current, and a surrogate for dissolved ions (e.g., total dissolved solids), can be modified due to hydrologic alterations. Specific conductance tends to increase during periods of low flow due to the lack of dilution and increased evaporation and groundwater inputs (Caruso, 2002). Groundwater pumping can increase salinity in streams and rivers by reducing base flows (Sheng and Devere, 2005). Vliet and Zwolsman (2008) documented changes in the concentrations of chloride, fluoride, sulfate, potassium, and the majority of other major ions during periods of low flow. Impoundments can have a dampening effect on seasonal variation for specific conductance when compared to a reference stream with no impoundment (Ahearn et al., 2005). Reduced flows can also change specific conductance due to saltwater intrusion in estuaries which can adversely affect sea grass and other biota.

Dams have been shown to have an effect on downstream concentrations of nutrients, Biological Oxygen Demand (BOD), and silicate, (Taleb et al. 2004; Pozo et al. 1997; Hannan and Young, 1974). Ammonium tends to increase in concentration downstream of impoundments, especially for dams with hypolimnetic releases (Ahearn et al., 2005; Taleb et al., 2004; Pozo et al., 1997; Hannan and Young, 1974). Reservoirs tend to act as sinks for dissolved silicon and total suspended solids (TSS) when compared to upstream concentrations (Ahearn et al., 2005; Higgins, 1978; Soltero et al., 1973; and Kelly, 2001).

Urban runoff has been shown to have increased concentrations of nutrients (Paul and Meyer, 2001; Mulholland et al., 2008; Grimm et al., 2005; Hatt et al., 2004; Morgan and Good, 1988) and ions (Helms et al., 2009; Morgan and Good, 1988). Urban runoff can also have elevated concentrations of legacy pesticides and other anthropogenic chemicals such as chlordane, dieldrin, PCB's, and toxaphene (Paul and Meyer, 2001; Parker et al., 2000), polycyclic aromatic hydrocarbons (PAH's) (Foster 2006, Delzer et al., 1996) and heavy metals (Soller et al., 2005; Paul and Meyer, 2001; Sansalone and Glenn 2000).

3.4.5 Effects on Biology

The direct effects of altered hydrology summarized in the previous section have been shown to cause indirect effects on the assessment endpoints of interest, namely the abundance and distribution of the aquatic life expected in a given waterbody or region (see Figure 1 generalized conceptual model). While biological responses to natural flow conditions can vary considerably, biological responses to anthropogenic hydrologic alterations are consistently negative, regardless of the direction and magnitude in flow alterations (McManamay et al. 2011).

Native fish species tend to respond negatively to hydrologic alterations, native algal species, and macroinvertebrates and riparian vegetation responses are variable (McManamay et al. 2011, Poff and Zimmerman 2009).

The timing of critical periods such as reproduction and spawning, and larval survival, growth, recruitment, and emergence are critical periods are linked to seasonal hydrologic patterns of the flow regime (Bunn and Arthington 2002). are synchronized with. The timing of flood peaks and seasonal flooding can play a crucial role in establishing fish community structure (Poff and Zimmerman 2009). Conversely, maintaining the natural timing of flood peaks can prevent establishment of non-native fish species. Changing the timing of flood peaks can increase the success of exotics. The timing of rising flows may serve as a spawning cue for certain fish species (Bunn and Arthington 2002). In contrast to high flow spawning, other aquatic species are cued to decreases in flow or the timing of low flows. Some fish species in lotic habitats recruit successfully by spawning in months of low stable stream flows to avoid scouring and or being stranded (Bunn and Arthington 2002).

Flow regulation that reduces the natural flow variability tends to favor the success of specific taxa (Poff et al. 1997). Altered flows in streams and rivers are frequently characterized by aquatic communities that are low in diversity (Bunn and Arthington 2002) and exhibit species traits characteristic of more lentic habitats (Carlisle et al. 2011). Regulation of flows and conversion of rivers to slow or still water habitat has been shown to affect diversity and the functional organization of fish communities, increasing the dominance of generalist fish species and favoring introduced species (Bunn and Arthington 2002). Generally, hydrologically variable streams are characterized by fish assemblages that are trophic and habitat generalists whereas, hydrologically stable streams are characterized by fish assemblages that are habitat and trophic specialists (Poff and Allen 1985). In particular, conversion of streams and rivers to lentic habitat has been shown to eliminate salmonids and pelagic spawning fishes, fishes adapted to turbid lotic habitats, and those fish species that utilize floodplain spawning grounds (Bunn and Arthington 2002; Dudley and Platania 2007).

Dewatering and other changes in flow magnitude have a significant negative impact on abundance, diversity, and population demographic parameters of aquatic organisms (Haxton and Findlay 2008; Poff and Zimmerman 2009). Fish consistently had negative responses to changes in flow magnitude, whether flows increased or decreased. Reducing the magnitude of floods increases the success of non-native fish species (Poff and Zimmerman 2009). Shallow nursery areas and the aquatic organisms that depend on them are greatly affected by fluctuating water levels caused by dewatering (Haxton and Findlay (2008). These dewatered areas decrease abundance of macroinvertebrates which would affect growth, recruitment, and eventually abundance. Water withdrawals and other hydrologic alterations that led to a reduction in base flows of XX% in Michigan resulted in a decreased abundance and diversity of fish species....(REFERENCE).

Macroinvertebrate communities are also vulnerable to rapid changes in flow as experienced below dams (Bunn and Arthington 2002). Dams that release water from the bottom (Hypolimnetic) have been associated with reduced macroinvertebrate abundance and species richness and can disrupt species emergence patterns due to the resulting modified temperature regime. Increasing frequency of high flow events can cause macroinvertebrate communities to shift toward species adapted to high mortality rates, such as short life cycles and/or high mobility (Poff et al. 2009).

Peak flow discharges associated with hydroelectric power generation and reservoirs for irrigation supply can limit the quality and quantity of habitat available and the associated rapid flow decreases can leave stream fish stranded on gravel bars or trapped in off-channel habitats (Bunn and Arthington 2002). Dams on water supply reservoirs tend to stabilize flows which results in a lack of natural extremes. This may act to increase abundance of a few species but at the expense of other native species (Poff et al. 1997).

4 Developing relations between streamflow alteration and aquatic life uses

The goal in developing relationships between streamflow alteration and aquatic life uses is to make generalizations—and predictions—about how ecological conditions respond to specific types and magnitudes of hydrologic alteration (as described in Chapter 3). The underlying basis of these predictions can vary greatly depending on the amount of information available. In cases where data from field studies and monitoring are available, the understanding may be grounded on statistical stressor-response models developed specifically to the stream type or geographic area of interest. In cases where scientific information is scarce, this understanding may be limited to generalizations from literature reviews or expert elicitation. Each approach represents opposite ends of the spectrum of possible choices for developing criteria for hydrologic condition, and will be discussed in greater detail below. The USEPA has provided guidance for developing quantitative models that support quantifying narrative criteria or establishing numeric criteria (e.g.,U.S. EPA 2000a, 2000b, 2001, 2008, 2010), which are adapted here for streamflow (Figure 8).

4.1 Identify Target Population

The initial step in translating narrative hydrologic criteria is identification of the population(s) of streams for which criteria are desired. Variation in natural factors such as climate, soils, topography, and geology create streams with unique hydrological, geomorphic, and biological characteristics even within relatively small geographic areas. This variation makes it unlikely that a single hydrologic condition criterion would be appropriate across the Nation or any single State. As a consequence, understanding the ecological consequences of hydrological alteration is probably most tractable if examined in streams that have similar hydrological, geomorphic, and ecological characteristics. Perennial streams within the state of California, for example, can originate from snowmelt-driven mountainous regions or the rainfall-dominated coastal ranges. The natural hydrologic regime and biological communities differ greatly between these two stream types, which suggests that the ecological responses to hydrological alteration also differ. As a result, hydrologic criteria developed for mountain streams would likely be inappropriate for coastal streams.

A population of streams—or stream type—can be defined using natural or management considerations, or both. Many jurisdictions have existing stream-type classifications in place, based on combinations of hydrologic, geomorphic, or ecological characteristics (e.g., Zorn et al. 2008). Ecoregions (sensu Omernik 1987) also provide a useful framework for identifying geographic areas with similar climate and topography—which are likely to have streams with similar characteristics. Unique stream types have also been identified using classification analyses with hydrological characteristics measured at streamgaging sites (e.g., Kennen et al. 2009), but there is growing recognition that inclusion of geomorphological or ecological characteristics improves the ecological relevance of hydrology-based classifications (Poff et al. 2010). Olden et al. (2011) provide a detailed discussion on the various classification methods and their inherent strengths and weaknesses.

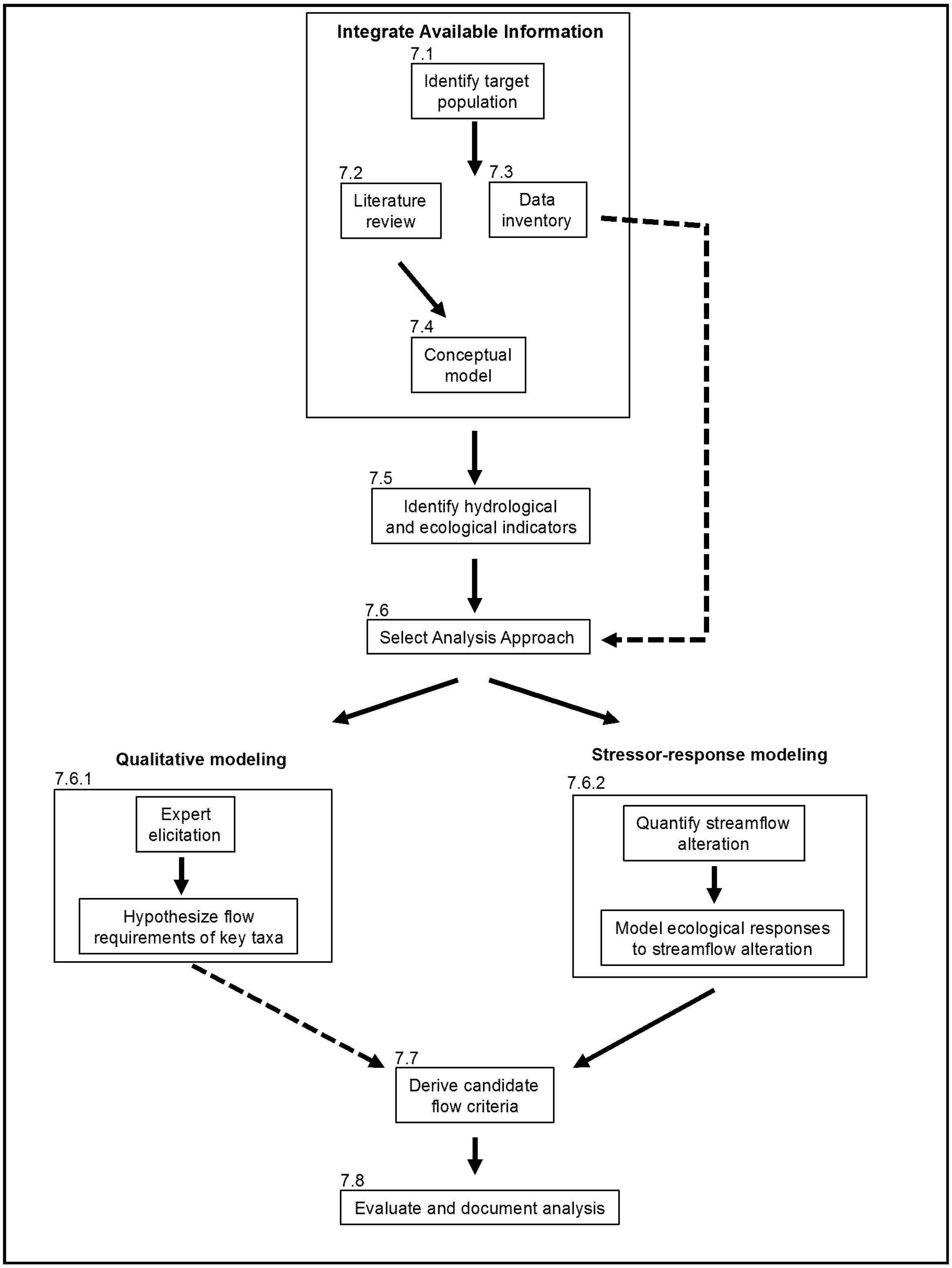


Figure 8. Framework for developing numeric hydrologic criteria for streams.

4.2 Literature Review

Having a target stream type identified will simplify efforts to synthesize relevant literature. Both published and unpublished literature should be gleaned with an eye towards understanding the streamflow requirements for species and ecological functioning of a stream type. Returning to the California example, a literature review of streams originating in the Sierra Nevada Mountains would reveal, among other generalities, that the timing, duration, and rate of change of the snowmelt recession is critical to the maintenance of animals such as the foothill yellow-legged frog (*Rana boylii*). The frog, which has been designated a species of concern in the state of California, lays its eggs in the shallow river margins in early spring, and subsequent hatchling survival requires a gradual decline in river flows through the summer (Yarnell et al., 2010).

Several global-scale literature reviews have been completed (e.g., Bunn and Arthington 2002, Poff and Zimmerman, 2009REFERENCES LIST), and provide general understanding in places where there is a paucity of data. Collectively, these global literature reviews have produced several generalities about the ecological effects of hydrological modification (see review in Section 6.x), but lack the quantitative and region-specific information from which to develop numeric criteria. The highest priority for literature reviews should be to seek and synthesize information that is specific to the population—or stream type—of interest.

Importantly, literature searches should not be limited to studies of streamflow alteration, but should include relevant work on species or biological communities relevant to aquatic life use designation and the suite of chemical or physical factors to which these organisms respond. For example, if the goal is to protect native fish communities, studies that reveal relationships between one of those species and water temperature, or that elucidate basic habitat requirements would be relevant to consider because these factors are strongly influenced by streamflows. In addition, studies that elucidate specific life-history requirements of target species should also be considered because such information would generate hypotheses (described in the conceptual model) about hydrological events that are important to the species' survival, growth, and reproduction.

4.3 Data Inventory

In addition to a literature review, existing data from the stream type/region of interest should be compiled and inventoried. The goal of the data inventory is to identify whether ecological responses to streamflow alteration can be evaluated for the focus stream type using only existing information (See "Select Analysis Approach" section below). The primary focus of the data inventory is to find biological (and associated chemical and physical) data that were collected at stream gaging stations or sites where streamflow can be estimated from nearby gages (SEE Appendix X for methods summary). The locations and watershed characteristics of a large proportion of streams gaged by the US Geological Survey can be obtained from recently published databases (Falcone et al. 2009, GAGES II). In some regions, models that simulate daily streamflows (see Poff et al., 2010) have been developed. Provided that model accuracy is acceptable, these models can be used to provide streamflow information at sites where biological data have been collected (Kendy et al., 2012).

State, federal, and other monitoring entities have collected biological community data from many thousands of stream sites across the Nation. Federal agencies and programs such as USEPA's regional and national assessments (USEPA 2007), USGS National Water-Quality Assessment Program, US Forest Service, and Bureau of Land Management have collected large amounts of biological data from streams across large regions. In addition, biological monitoring data collected by state agencies are also generally available. Because stream types often cross political boundaries, biological data from multiple monitoring entities should be considered. An important consideration in the use of biological monitoring data from multiple entities is compatibility of the data given differences in sampling methods. Potential differences in methods are many, and include the habitats sampled (e.g., multi-habitat vs. targeted riffles), sampling effort (e.g., size of area sampled), sampling device, and the handling of taxonomic data (e.g., target taxonomic resolution). Methodological differences should be considered in light of the level of resolution at which the data will be combined. As a general rule, data combined at the most resolved level of taxonomic names and counts is more susceptible to methodological differences, whereas data combined at progressively coarser levels are less susceptible. Nevertheless, even subtle methodological differences can complicate analyses using compiled data. For example, Carlisle and Hawkins (2008) found that subtle differences in sampling effort between two data sets caused a systematic bias of up to 10% in the values of a biological indicator that is based on the presence/absence of macroinvertebrate taxa. A thorough discussion of data compatibility issues is provided in Cao and Hawkins (2011), which readers are strongly encouraged to consult ***prior*** to efforts to combine biological monitoring data from multiple sources.

The data compilation and inventory effort will likely identify opportunities for new biological data collection at gaged sites, as well as the overall lack of gaging in some strata of the target stream type—e.g., first-order streams. Because the stream gaging network is limited to about 7,000 stream sites and is biased towards medium to large streams and rivers (Poff et al. 2006), there is often a small proportion of sites where biological and streamflow data overlap spatially. In addition, the temporal overlap of streamflow and biological data are often limited because the length and period of streamflow records varies greatly from gage to gage. Additional targeted biological monitoring may be necessary at active streamgage sites within the stream type of interest.

4.4 Develop Conceptual Models

The conceptual model presented in Sec. 6.2 is an explicit summary of the state of knowledge about relationships between human activities, streamflow alteration, and various interacting ecological responses. A conceptual model can be represented as a diagram and, with an accompanying narrative, can be a useful guide in developing numeric criteria for two reasons: they depict accepted scientific knowledge, and they help guide model development.

First, conceptual diagrams depict accepted scientific knowledge about the ecological effects of streamflow alteration. The causal pathways that lead from human activities to altered streamflows to impacts on designated uses have been investigated in the scientific literature (e.g.,EXAMPLES in Chapter 3). To assist practitioners in developing their own models, a generalized conceptual model was provided in this document (Chapter 3.1) that describes the known causal pathways connecting streamflow alteration to impacts on aquatic life designated uses. (Additional region-specific conceptual model examples are described in Appendix F.)

Conceptual models also help guide the development of stressor-response models, which quantify the ecological responses to streamflow alteration and are the basis for quantifying criteria. Conceptual models identify relationships that can be modeled with statistical analyses and help analysts identify the important variables to consider during the analysis phase. In particular, conceptual models provide a means of identifying confounding variables, which are defined as variables that can influence estimates of the stressor-response relationships. This emphasis on identifying potentially confounding variables dictates that the diagrams include other pathways linking human activities to biological responses and designated uses, which is a slightly different emphasis than conceptual models developed for other purposes. Hence, the conceptual models needed here more comprehensively describe both flow-related and non-flow related causal pathways linking human activities to designated uses. However, all relevant pathways cannot be included in the model diagrams provided here, and it is expected that analysts would modify these diagrams by adding or removing concepts and pathways based on the details of a particular location or system (see Appendix B for region-specific examples). More generalized conceptual model diagrams with more detailed pathways can be found at http://www.epa.gov/caddis, where the development of conceptual models is presented as key step in stressor identification.

4.5 Identify Hydrological and Ecological Indicators

Selection of the most appropriate hydrological and ecological indicators is simplified once the conceptual models are developed. Conceptual models should identify which specific streamflow attributes are relevant to key species and communities. For example, a conceptual model developed for Sierra Nevada streams would indicate that the rate of flow decline after snowmelt controls the population dynamics of riparian plants and key amphibian species. Hence, a measure of the recession rate would be an appropriate hydrological indicator, and the populations or recruitment success of affected species would be appropriate ecological indicators.

The valued ecological resources of concern in this document are aquatic life uses; for example, the diversity and abundance of native aquatic macroinvertebrates, fish, and other aquatic flora and fauna. The indicators of the condition of the aquatic life may be ecologically relevant hydrologic conditions or flow metrics such as flow magnitudes (e.g., peak flows, low flows, or flows associated with a key life-history stage of an organism such as reproduction). Therefore, flow metrics can be viewed as the indicators (measurement endpoints) that characterize the environment under which there may be deleterious effects on biological conditions. Specific measures of biological condition indicative of CWA aquatic life uses (e.g., relative abundance of certain sensitive taxa, biomass of certain species, or biological metrics such as taxa richness) are the measures of effect used to relate hydrologic conditions (measurement endpoints) to the assessment endpoints.

The hydrological regime of streams and rivers is typically characterized with a suite of statistics that are computed from time series of daily flow values. Using daily flow time series, a large number of statistics can be calculated that characterize broad features of the hydrological regime including the magnitude, frequency, duration, rate of change, and timing of flows. Several tools that calculate streamflow statistics are publicly available (IHA, HIT/HAT, etc.). Because the hydrological regime can be characterized with so many statistics, it is necessary to select a subset of statistics that are appropriate for a given objective.

In general, there are several considerations when selecting streamflow statistics. First, a statistic should be relevant to the management goal of the water body. If the goal is to maintain or enhance ecological health (e.g., protect aquatic life designated uses), it is imperative to identify the streamflow characteristics critical to the populations, communities, and ecosystems of interest. Again, these relationships should be a key product of the conceptual models discussed above. A second, and related, consideration is the relevance of streamflow statistics to resource managers and the public. The management and societal relevance of a given statistic is considerably higher if it is interpretable and easy to communicate, and represents a characteristic of flow that is under the direct influence of management actions.

4.6 Select Analysis Approach

Previous EPA guidance documents describe general types of analyses that can be used to derive criteria (US EPA 2000a, 2000b). A recent review (Kendy et al. 2012) highlights several case studies aimed at developing numeric streamflow criteria throughout the United States. In general, these case studies have adopted one or two general approaches. First, in cases where biological and matching hydrological data are scarce (see Data Inventory, Step 4.3), hypothetical qualitative (and in some cases, quantitative) streamflow needs for specific target species have been identified based on expert elicitation (Section 4.6.1). This approach is hereafter referred to as "Qualitative Modeling," even though some aspects employ quantitative information (but not specific stressor-response modeling). "Quantitative Modeling" constitutes the second general approach, appropriate when data are available and stressor-response relationships between flow alteration and various biological measures can be modeled (Section 4.6.2). The Data Inventory step, described above, provides the key information in selecting the analysis approach. The analysis approach taken is limited by the availability of data. Quantitative modeling requires more data—and high confidence in data quality—relative to qualitative modeling.

4.6.1 Qualitative Modeling

In many cases there is inadequate empirical data for quantitative modeling for a geographic area or stream type. Although the science is progressing and new quantitative models continue to emerge (e.g., Merritt and Poff 2010), qualitative models based on generalizations and hypotheses drawn from the literature and expert elicitation may be the best available alternative. Qualitative models, as defined here, include a wide range of approaches aimed at setting criteria to protect flow for aquatic life uses when available data are inadequate for quantitative modeling.

One approach, known as the "presumptive standard", uses case studies and literature reviews to hypothesize that ecological values are protected if stream flows are maintained within a specific range (i.e., percentage) of natural conditions (Richter, 2009; Richter et al., 2011). This approach is proposed to serve as an interim standard until data are sufficient to use quantitative modeling for quantifying criteria tailored to a specific stream type or region (Figure 9). Richter et al. (2011) also review case studies where states and other jurisdictions have applied presumptive standards in management and decision-making.

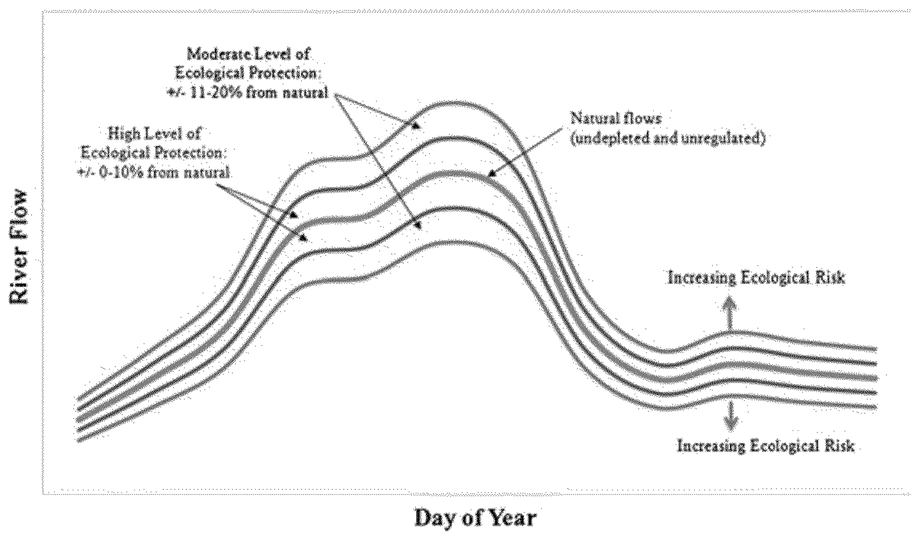


Figure 9. The Presumptive Standard hypothesizes that ecological values are protected if daily flows are maintained within a specific percentage of natural conditions. The likelihood of ecological

impairment increases with greater departure from the natural condition (COPIED from Richter et al., 2011).

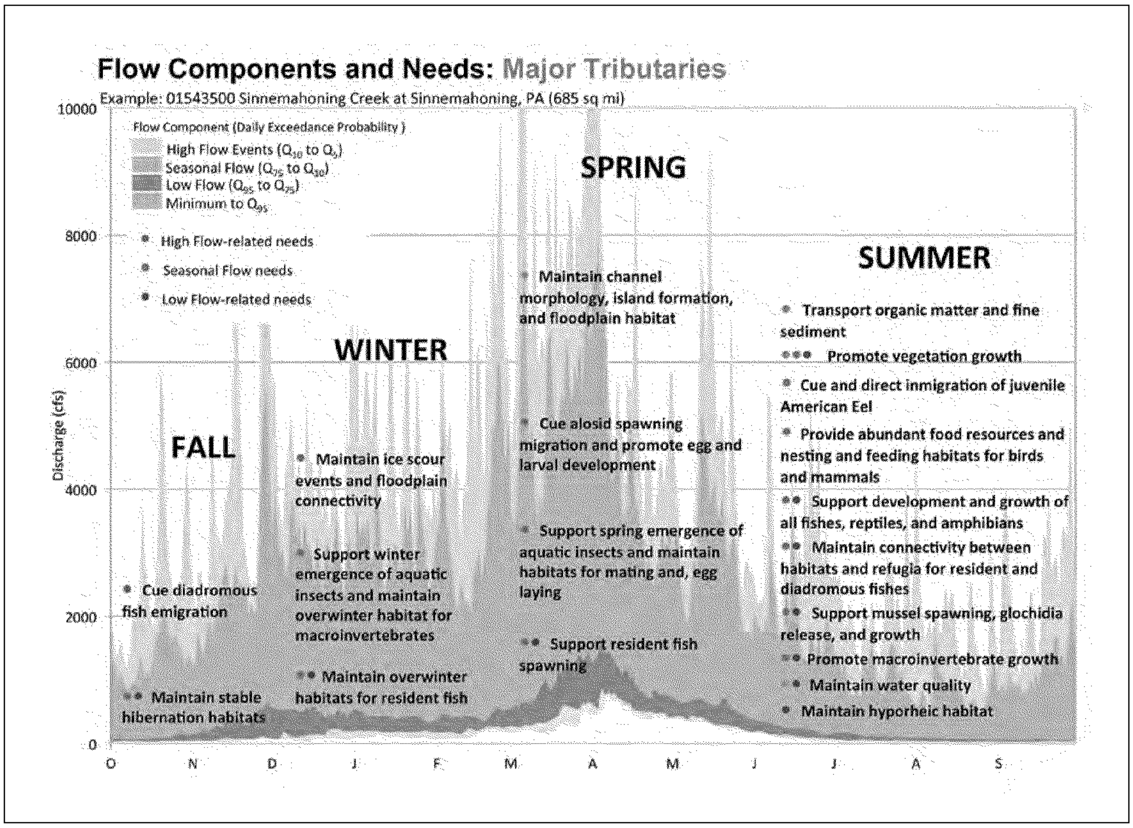


Figure 10. Graph showing ecological functions and aquatic species that depend on the natural seasonal flow regime in the Susquehanna River basin (COPIED from Kendy et al).

Another qualitative approach is the use of literature reviews, conceptual models, and expert elicitation to hypothesize flow needs for specific species or communities. In this approach, hydrographs that represent natural conditions of the target stream type are juxtaposed to life-history stages of key native species. Experts can then identify the time periods when specific streamflow characteristics are needed for successful growth and reproduction of these species, which leads to hypotheses about how streamflow alteration influences aquatic life (Figure 10. Examples of this approach are presented in Kendy et al. (2012).

4.6.2 Stressor-Response Modeling

Quantitative stressor-response relationships between streamflow alteration and ecological endpoints can be established in circumstances where ecological data are available from streams where daily streamflow data also exist. The goal of this modeling is prediction of the ecological response to varying degrees of streamflow alteration (Figure 7-4). There is a wide range of statistical tools with which to develop models predicting the ecological response to some stressor, and these will not be reviewed in this document. Readers are highly encouraged to consult the in-depth review of these methods by Yuan et al. (2010). This section will focus on the nuances of stressor-response modeling where streamflow alteration is the key stressor.

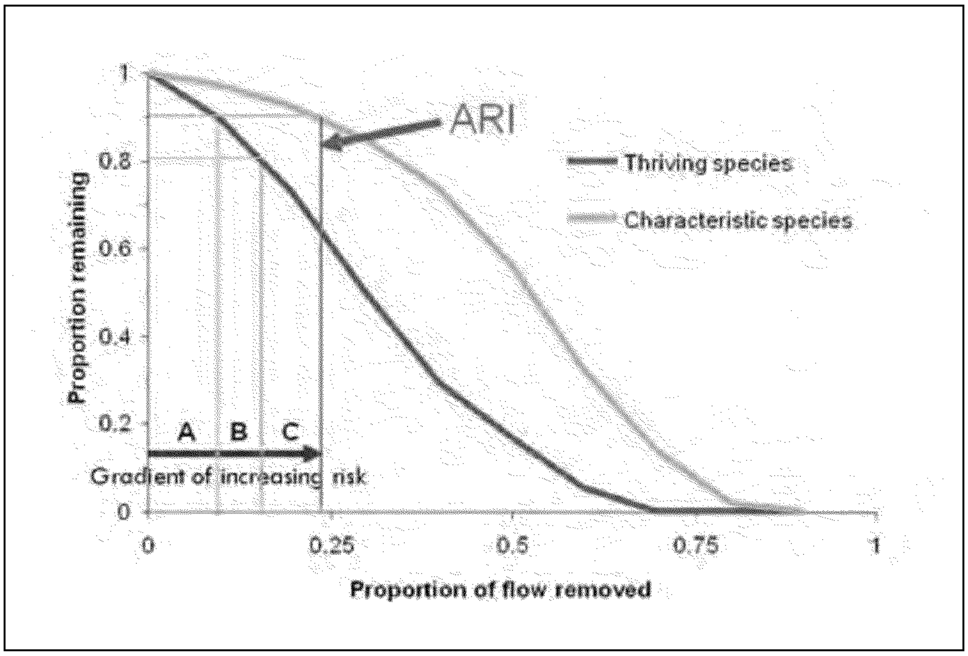


Figure 11. Curves depicting predicted response of fish communities to increased removal of August streamflows in Michigan streams (COPIED from Kendy et al. 2012).

A fundamental need in developing stressor-response models is quantifying the stressor—which in this case is streamflow alteration. Alteration is defined as the deviation of observed conditions from expected baseline, or reference, conditions (Richter 1997), with respect to each streamflow attribute of interest. Three important principles are relevant to this effort.

The first principle to consider in quantifying streamflow alteration is the selection of the appropriate hydrological indicators. This effort should be guided by the science at hand, which is derived from the literature review, conceptual models, and expert elicitation (see Section 7.5, Identifying hydrological and ecological indicators). It is likely that for any given stream there are a number of hydrological indicators that may be simultaneously altered, but in different ways. For example, a stream influenced by a flood control reservoir is likely to have high flows that are less than baseline and, as the water is later released during the dry season, low flows that are greater than baseline (Poff et al. 2007, Carlisle et al. 2010). Finally, it is likely that any number of selected hydrological indicators will be highly correlated, so there should be thought about whether or not to develop separate models for redundant hydrological indicators. For example, annual high flows may be redundant with the median May flows in streams that have predictable snowmelt runoff during that month. Developing separate models for redundant hydrological indicators may still be justified if each indicator is relevant to a different management practice or ecological endpoint.

A second principle in stressor-response modeling is the need to establish baseline conditions—that is, the expected hydrological and ecological conditions under minimal or no human influence (sensu Stoddard et al. 2008). The expected baseline condition of hydrological indicators can be estimated in a number of ways (See Box 4-1), including mechanistically (e.g., Kennan et al. 2008) or with a variety of statistical techniques (e.g., Archfield et al., 2010; Carlisle et al., 2010). Depending on the spatial scale of analysis and ecological endpoint, expected baseline or reference conditions may be necessary for the ecological indicators as well as the hydrologic indicator. Given that the composition of biological communities varies greatly across natural gradients such as stream size and channel slope, the influence of natural factors on the response variable must be accounted for in quantitative modeling (see also Yuan et al., 2010).

Finally, as in any stressor-response modeling, there are several important caveats when developing models for streamflow alteration. Foremost is that there are likely other physical and chemical stressors—both measured and unmeasured—that influence biological communities in hydrologically altered streams. Therefore, certainty in the establishment of causation is low. In general, the evidence for causation in correlative relations is strongest if the influence of potential natural and anthropogenic factors is somehow controlled in the analysis or design (see various techniques in Yuan et al., 2010). An additional caveat is that the lack of strong ecological responses does not necessarily mean that none exists. The influence of other factors—as just described, misspecification of streamflows, or excessively noisy ecological data, can all obscure real underlying relationships between altered flows and ecological integrity. Therefore, the finding of “no relation” should be followed up by additional verification.

BOX 4-1. Estimating Baseline Streamflow Conditions

Baseline hydrological conditions for streams have been estimated using a wide range of methods, but are based on two general approaches: simulations of daily streamflows or predictions of streamflow characteristics. The approach used is largely driven by the information needs and available resources.

One approach to estimating baseline streamflow conditions is the use of mechanistic/process models that simulate daily flows. These models typically employ measured precipitation to estimate daily runoff and streamflows given other factors such as air temperature, soil properties, and land cover for a specific river basin or small region (see review in Poff et al. 2010). After the models are developed and calibrated to measured streamflow at existing gages, baseline streamflow is estimated by removing the modeled effects of human impacts such as impervious cover and water withdrawls. Mechanistic/process models provide the most complete streamflow information available for un-gaged streams, but typically require more data and resources to develop than other methods.

The other approach to estimating baseline streamflow conditions is the use of statistical models to predict streamflow characteristics (e.g., annual maximum daily flow). Streamflow characteristics are calculated and summarized (e.g., over 10-15 years) from records at gages within minimally disturbed watersheds. Then, statistical models are developed that use watershed characteristics such as climate, topography, geology, and soils are to predict streamflow statistics at minimally disturbed sites. Because the models are developed using a large number of minimally disturbed sites and use predictor variables that are largely uninfluenced by humans, the models can then be applied to predict baseline streamflow characteristics in streams with known human influences. Carlisle et al. (2010) illustrate this approach using a wide variety of streamflow characteristics, and Archfield et al. (2011) illustrate this approach using attributes of flow-duration curves. These statistical models are simple to develop and use at different spatial scales, but provide a limited amount of hydrological information (i.e., statistics only) relative to mechanistic/process models.

4.7 Quantitative Translation of Candidate Criteria

The desired outcome of quantitative stressor-response modeling is elucidation of relationships between desired ecological endpoints and varying levels of streamflow alteration, as depicted in Figure 7-4, which can be readily translated into specific criteria for hydrologic condition. Kendy et al. (2012) provide many useful suggestions for accomplishing this goal. One important step in particular is to define ecological goals and risk levels in terms of the ecological metrics used in the quantitative modeling. This will ensure that model predictions can be directly translated into protection of aquatic life use goals. Ideally, the ecological response variable in quantitative models is an indicator of aquatic life use attainment, such as an Index of Biological Integrity, for which decision thresholds have been established. For example, the quantitative relationship shown in Figure 12 reveals how biological condition, as a measure of aquatic-life use attainment, is related to depletion of winter baseflows in Utah streams (Carlisle et al., 2012).

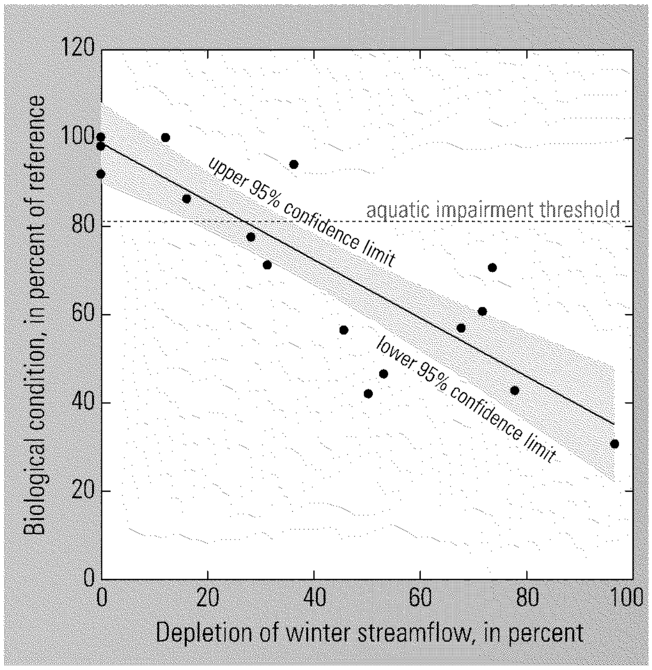


Figure 12. Modeled relationship between biological condition (defined as taxonomic completeness of macroinvertebrate communities, in percent) and depletion of winter baseflows in Utah mountain streams (Carlisle et al., 2012). The aquatic impairment threshold was established by the state for use in biological assessments to indicate probable impairment of aquatic-life use.

Because the ecological endpoint in the modeling process is already used to assess aquatic-life use attainment by the state, quantitatively translating a candidate criterion for hydrologic condition would be relatively straightforward. In this particular case, winter baseflow depletions exceeding 25 percent (with confidence intervals of 18-40 percent) are likely to result in biological impairment.

4.8 Evaluate and Document Analysis

Candidate criteria based on quantitative stressor-response models should be systematically evaluated for scientific defensibility. In particular, consideration (in the context of hydrologic condition) should be given as to whether the estimated relationships between streamflow alteration and ecological responses accurately represent known relationships and are sufficiently precise to inform decision-making. Specific recommendations for this evaluation are given by Yuan et al. (2010), and include 1) evaluation of model accuracy and, 2) model precision; 3) consideration of implementation issues; and 4) documentation of analyses. Each is briefly summarized here.

The accuracy with which a stressor-response model represents true underlying relationships is largely influenced by the influence of confounding factors—measured or unmeasured factors that are systematically related to the stressor or the response variable. The identity of possible confounding factors should be revealed in conceptual models before the analysis phase (see section 7.6), but analysts should evaluate and document the potential influences of these confounding factors on the stressor-response relationships. Approaches for doing this are given in Yuan et al. (2010).

The precision of an estimated stressor-response model influences its usefulness in decision-making. Two types of precision are discussed by Yuan et al. (2010) and relevant to streamflow criteria: precision in predictions based on the stressor-response model, and precision in the estimates of the parameters that define the relationship.

The primary issue to consider with respect to implementation is whether the stressor-response models can be applied to all streams within the desired population (see Section 7.1). This is particularly an issue if, during the model development process, various classifications or data sub-setting were required to control for confounding variables (see Yuan et al. 2010).

Finally, the quantitative modeling process should be thoroughly documented, peer reviewed, and made available to the public. Yuan et al. (2010) provide additional details.

5 Eco-Flows and Decision-Making

The goal in knowing the ecological responses to streamflow alteration is to inform the decision-making process. Eco-flow relations inform decisions primarily by explicitly identifying the expected ecological outcomes of alternative choices in water management. Assuming that the eco-flow relations are based on hydrological characteristics that are relevant to management, and that the ecological endpoint represents a specific value of the ecosystem (i.e., aquatic life designated uses), such relations provide information to make transparent choices about the needs of society while protecting health of ecosystems.

5.1 Stakeholder involvement

5.2 Global change considerations

Hydrologic alteration due to climate change and associated changes to the water cycle will influence water chemistry and sediment loads (Kundzewicz et al., 2007). In North America, projected changes in average stream flow range from an increase of 10–40% (at high latitudes) to a decrease of about 10–30% (in mid-latitude western North America) by 2050 (Milly et al., 2008).

Climate change effects on rivers and streams makes it unreasonable to use historic patterns of natural variability to predict future variability, or to use as a basis for calculating water needs and guiding management (Milly et al. 2008; US Global Change Research Program, 2009). The number of waterbodies that are considered to be "impaired" are expected to increase (USEPA, 2008a, 2008b). The need to modify operational rules of dams and diversions and to adjust water allocations among users is likely to be a critical necessity for the protection of infrastructure and public safety, to ensure reliability of water delivery, and to protect the physical, chemical, and biological integrity of our nation's waters.

6 References

From Ch. 1-4

Stalnaker, CB. 1990. Minimum flow is a myth. Ecology and assessment of warmwater streams: Workshop synopsis. M.B. Bain, p. 31-33. Biol. Report 90(5). U.S. Fish and Wildlife Service. Washington, D.C.

Hill, M.T., W.S. Platts, and R.L. Beschta. 1991. Ecological and geological concepts for instream and out-of-channel flow requirements. Rivers 2(3): 198-210.

The Intergovernmental Task Force on Monitoring Water Quality. 1995. The strategy for improving water quality monitoring in the United States. Technical appendix D: Indicators for meeting management objectives- summary and rationale matrices.

Postel, S. and B. Richter. 2003. Rivers for Life: Managing Water for People and Nature. Island Press. Washington, D.C. pp. 253.

U.S. EPA. 1994. Water Quality Standards Handbook: Second Edition. http://water.epa.gov/scitech/swguidance/standards/handbook/index.cfm

U.S. EPA 2002. Consolidated Assessment and Listing Methodology- Toward a Compendium of Best Practices. http://water.epa.gov/type/watersheds/monitoring/calm.cfm

U.S. EPA 2005. Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act. 89 pp. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/2006irg-report.pdf

Gende, S.M., R.T. Edwards, M.F. Willson, and M.S. Wipfli. 2002. Pacific salmon in aquatic and terrestrial ecosystems. BioScience 52(10): 917-928.

Angermeier, P.L. and M.R. Winston. 1998. Local vs. regional influences on local diversity in stream fish communities of Virginia. Ecology 79: 911-927.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. Freeman and Company, San Francisco.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199–214.

Montgomery, D.R. 1999. Process Domains and the River Continuum. J. of the American Water Resources Association. 35(2): 397-410.

Maxwell, J. R., C. J. Edwards, M. E. Jensen, S. J. Paustian, H. Parrott, and D. M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). U.S. Forest Services, General Technical Report NC-176, St. Paul, Minnesota.

Osborn, L.L. and M.J. Wiley. 2011. Influence of tributary spatial position on the structure of warmwater fish communities. Canadian Journal of Fisheries and Aquatic Sciences 49(4): 671-681.

Wang, L. and P.W. Seelbach. 2006. Introduction to Landscape Influences on Stream Habitats and Biological Assemblages. Amer. Fisheries Society Symposium. 48: 1-23.

Wiley, M. J., S. L. Kohler, and P. W. Seelbach. 1997. Reconciling landscape and local views of aquatic communities: lessons from Michigan trout streams. Freshwater Biology 37:133–148.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130–137.

References from Stressor/Source

Armstrong, D.S., Richards, T.A., and Levin, S.B., 2011, Factors Influencing Riverine Fish Assemblages in Massachusetts, USGS Scientific Investigations Report p. 2011-5193

Baron, J.S., N.L. Poff, P.Pl. Angermeier, C.N. Dahm, P.H. Gleick, N.G. Hariston, Jr., R.B. Jackson, C.A. Johnston, B.D. Richter, and A.D. Steinman. 2002. Meeting ecological and societal needs for freshwater. Ecological Applications 12:1247-1260.

Blann KL, Anderson JL, Sands GR, and Vondracek B, 2009, Effects of agricultural drainage on aquatic ecosystems: a review, Critical Reviews in Environmental Science and Technology 39: 909-1001.

Bradford, M.J. and J.S. Heinonen. 2008. Low flows, instream needs and fish ecology in small streams. Canadian Water Resources Journal 33(2): 165-180.

Brooks, B.R., Riley, T.M., and R.D. Taylor. 2006. Water quality of effluent-dominated ecosystems: ecotoxological, hydrological, and management considerations. Hydrobiologia 556(1): 365-379.

Cassie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology 51:1389-1406.

Collier, M., R.H. Webb, and J.C. Schmidt. 1996. Dams and rivers: A primer on the downstream effects of dams. US Geological Survey Circular 1126, Tucson, Arizona.

Dynesius, M. and C, Nilsson. 1994. Fragmentation and flow regulation of the river systems in the northern third of the world. Science 266:753-762.

Graf, W.L. 1999. Dam nation: a geographic census of American dams and their large-scale hydrologic impacts. Water Resources Research 35:1305-1311.

Harr RD, Levno A, Mersereau R, 1982, Streamflow changes after logging 130-year old Douglas fir in two small watersheds, Water Resources Research 18: 637-644.

Hewlett JD, Hibbert AR, 1961, Increases in water yield after several types of forest cutting, Hydrological Sciences Journal 6: 5-17.

Johnson, P.T.J., J.D. Olden, and M.J. Vander Zanden. 2008. Dam invaders: impoundments facilitate biological invasions into freshwaters. Frontiers in Ecology and the Environment 6:357-363.

Konrad CP, Booth DB, 2005, Hydrologic changes in urban streams and their ecological significance, p. 157-177, in Brown LR, Gray RH, Hughes RM, and Meador MR (eds.), Effects of urbanization on stream ecosystems.

Magilligan, F.J. and K.H. Nislow. 2005. Changes in hydrologic regime by dams. Geomorphology 71:61-78.

Olden, J.D. and R.J. Naiman. 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshwater Biology 55: 86-107.

Poff, N.L., J.D. Olden, D.M. Merritt, and D.M. Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. Proceedings of the National Academy of Science. 104:5732-5737.

Reeves, H. W., D. A. Hamilton, P. W. Seelbach, and A. J. Asher. 2009. Ground-Water-Withdrawal Component of the Michigan Water-Withdrawal Screening Tool. U.S. Geological Survey, Scientific Investigations Report 2009-5003, Reston, Virginia. Available: 5/2011 at http://pubs.usgs.gov/sir/2009/5003/.

Roy, A.H., Freeman, M.C., Freeman, B.J., Wenger, S.J., Ensign, W.E., and Meyer, J.L., 2005, Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams: Journal of the North American Benthological Society, v. 24, p. 656–678.

Roy, A.H., Purcell, A.H., Walsh, C.J., and Wenger, S.J., 2009, Urbanization and stream ecology—Five years later: Journal of the North American Benthological Society, v. 28, no. 4, p. 908–910.

Wang, L., Infante, D., Lyons, J., Stewart, J., and A. Cooper. 2011, Effects of dams in river networks on fish assemblages in non-impoundment sections of rivers in Michigan and Wisconsin, USA: River Research and Applications, v. 27, p. 473–487.

Wenger, S.J., Peterson, J.T., Freeman, M.C., Freeman, B.J., and Homans, D.D., 2008, Stream fish occurrence in response to impervious cover, historic land use, and hydrogeomorphic factors: Canadian Journal of Fisheries and Aquatic Sciences, v. 65, p. 1250–1264.

Zarriello, P.J., and Ries, K.G., III. 2000. A precipitation runoff model for analysis of the effects of water withdrawals on streamflow, Ipswich River basin, Massachusetts: U.S. Geological Survey Water-Resources Investigation Report 00-4029, 99 p.

Zimmerman, J.K.H, Letcher, B.H., Nislow, K.H., Lutz, K.A., and Magilligan, F.J., 2009, Determining the effects of dams on subdaily variation in river flows at a whole-basin scale, *River Research and Applications* v. 26 p.1246-1260.

Zorn, T.G., Seelbach, P.W., Rutherford, E.S., Wills, T.C., Cheng, S.-T., and Wiley, M.J., 2008, A regional-scale habitat suitability model to assess the effects of flow reduction on fish assemblages in Michigan streams: Ann Arbor, Mich., Michigan Department of Natural Resources, Fisheries Research Report 2089, 46 p. OR in JAWRA below:

Zorn, T.G., Seelbach, P.W., and E.S. Rutherford. 2012. A regional-scale habitat suitability model to assess the effects of flow reduction on fish assemblages in Michigan streams. J. of the Amer. Water Resources Association. 1-25. DOI: 10.1111/j.1752-1688.2012.00656.x

References from Appendix E

Olden, Julian D., Mark J. Kennards and Bradley J. Pusey. 2011. "A framework for hydrologicclassification with a review of methodologies and applications in ecohydrology."Ecohydrology.

Poff, Leroy N., Brian D. Richter, Angela H. Arthington, Stuart E. Bunn, Robert J. Naiman, Eloise Kendy, Mike Acreman, Colin Apse, Brian P. Bledsoe, Mary C. Freeman, James Henriksen, Robert B. Jacobson, Jonathan G. Kennen, David M. Merritt, Jay H. O'keeffe, Julian D.Olden, Kevin Rogers, Rebecca E. Tharme and Andrew Warner. 2010. "The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards." Freshwater Biology. 55: 147-170.

Sanborn, Stephen C. and Brian Bledsoe. 2006. "Predicting streamflow regime metrics for ungauged streams in Colorado, Washington, and Oregon." Journal of Hydrology. 325:241-261.

Thompson, J.R., M.P. Taylor, K.A. Fryirs, and G.J. Brierley. 2001. "A geomorphological framework for river characterization and habitat assessment." Aquatic Conservation:Marine and Freshwater Ecosystems. 11: 373-389.

From Conceptual Model

U.S. EPA 1998 Guidelines for Ecological Risk Assessment. U.S. Environmental Protection Agency, Washington, DC. EPA/630/R-95/002F.

U.S. EPA 2002. Consolidated Assessment and Listing Methodology- Toward a Compendium of

Best Practices. http://water.epa.gov/type/watersheds/monitoring/calm.cfm

U.S. EPA 2005. Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act. 89 pp. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/2006irg-report.pdf

References from Water Quality (to be completed)

Ahearn, D.S., R.W. Sheibley, and R.A. Dahlgren. 2005. Effects of river regulation on water quality in the lower Mokelumne River, California. River Research and Applications 21(6): 651-670.

Bolke, E. and K. Waddell. 1975. Chemical quality and temperature of water in Flaming Gorge Reservoir, Wyoming and Utah, and the effect of the reservoir on the Green River, Water Supply Paper 2039-A, 1975. 26 P, 8 FIG, 1 PLATE, 1 TAB, 9 REF.

Caruso, B. S. 2002. Temporal and spatial patterns of extreme low flows and effects on stream ecosystems in Otago, New Zealand. Journal of Hydrology 257(1-4): 115-133.

Crisp, D. 1977. Some physical and chemical effects of the Cow Green (Upper Teesdale) impoundment. Freshwater Biology 7(2): 109-120.

Hannan, H. H. and W. J. Young. 1974. The influence of a deep-storage reservoir on the physicochemical limnology of a Central Texas River. Hydrobiologia 44(2): 177-207.

Helms, B. S., J. E. Schoonover, and J.W. Feminella. 2009. Assessing influences of hydrology, physicochemistry, and habitat on stream fish assemblages across a changing landscape. JAWRA Journal of the American Water Resources Association 45(1): 157-169.

Lieb, D. A. and R. F. Carline. 2000. Effects of urban runoff from a detention pond on water quality, temperature and caged Gammarus minus (Say) (Amphipoda) in a headwater stream. Hydrobiologia 441(1): 107-116.

Pozo, J., E. Orive, H. Fraile, and A. Basaguren. 1997. Effects of the Cernadilla-Valparaiso reservoir system on the River Tera. Regulated Rivers: Research & Management 13(1).

Sheng, Z. and J. Devere. 2005. Understanding and managing the stressed Mexico-USA transboundary Hueco bolson aquifer in the El Paso del Norte region as a complex system. Hydrogeology Journal 13(5): 813-825.

van Vliet, M.T.H. and J.J.G. Zwolsman 2008. Impact of summer droughts on the water quality of the Meuse river. Journal of Hydrology 353(1-2): 1-17.

Zwolsman, J., A. van Bokhoven, and L.J. Bolwidt. 2007. Impact of summer droughts on water quality of the Rhine River- a preview of climate change?, IWA Publishing, Alliance House 12 Caxton Street London SW 1 H 0 QS UK. 56.

7 Appendix A: Legal Background and Relevant Caselaw

EPA is issuing this document pursuant to CWA sections 304(a)(2) and 304(f). CWA section 304(a)(2) generally authorizes EPA to develop and publish information on the factors necessary to restore and maintain the chemical, physical, and biological integrity of navigable waters. Section 304(a)(2) also permits EPA to provide information on the factors necessary for the protection and propagation of shellfish, fish, and wildlife of receiving waters and to allow recreational activities in and on the water.[1] CWA section 304(f) authorizes EPA to issue information to control pollution resulting from, among other things, "changes in the movement, flow, or circulation of any navigable waters".

EPA notes that it has been argued "that the CWA is only concerned with water 'quality,' and does not allow the regulation of water 'quantity.'" *PUD No. 1 of Jefferson County, et al. v. Washington Department of Ecology (PUD)*, 511 U.S. 700, 719-21 (1994). The U.S. Supreme Court, however, has held that the distinction between water quality and water quantity is "artificial", explaining that "[i]n many cases, water quantity is closely related to water quality; a sufficient lowering of the water quantity in a body of water could destroy all of its designated uses, be it for drinking water, recreation, navigation or … as a fishery." *Id.*

The Supreme Court in *PUD* cited to various provisions of the CWA that recognize that "reduced stream flow, i.e., diminishment of water quantity, can constitute water pollution", including the Act's definition of "pollution" as "the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water". See *id.* (citing to CWA section 502(19)). The Supreme Court held that "[t]his broad conception of pollution – one which expressly evinces Congress' concern with the physical and biological integrity of water – refutes petitioners' assertion that the Act draws a sharp distinction between the regulation of water 'quantity' and water 'quality'". See *id*; see also *S.D. Warren Co. v. Maine Board of Environmental Protection*, 547 U.S. 370, 385 (2006) ("Congress passed the Clean Water Act to 'restore and maintain the chemical, physical, and biological integrity of the Nation's waters' … the 'national goal' being to achieve 'water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water,' …. To do this, the Act does not stop at controlling the 'addition of pollutants,' but deals with

[1] EPA notes that CWA section 304(a)(2) is distinct from CWA section 304(a)(1), which authorizes EPA to "develop and publish … criteria for water quality accurately reflecting the latest scientific knowledge (A) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, esthetics, and recreation which may be expected from the presence of pollutants in any body of water, including ground water; (B) on the concentration and dispersal of pollutants, or their byproducts, through biological, physical, and chemical processes; and (C) on the effects of pollutants on biological community diversity, productivity, and stability, including information on the factors affecting rates of eutrophication and rates of organic and inorganic sedimentation for varying types of receiving waters."

'pollution' generally … , which Congress defined to mean 'the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water[.] The alteration of water quality as thus defined is a risk inherent in limiting flow and releasing water through turbines. Warren itself admits that its dams "can cause changes in the movement, flow and circulation of a river … caus[ing] a river to absorb less oxygen and to be less passable by boaters and fish. … Changes in the river like these fall within a State's legitimate legislative business, and the Clean Water Act provides for a system that respects the State's concerns)".

The Supreme Court in *PUD* also addressed CWA sections 101(g) and 510(2), which have been relied on, at times, in efforts to restrict regulation of water quantity and flow pursuant to the CWA. *PUD* at 719-21. The petitioners in that case argued that sections 101(g) and 510(2) of the CWA exclude the regulation of water quantity from the coverage of the CWA, specifically arguing that "these provisions exclude 'water quantity issues from direct regulation under the federally controlled water quality standards in § 303.'" *PUD* at 1913 (quoting Brief for Petitioners 39).

The Supreme Court noted the peculiarity of the petitioners' argument that these provisions (which give the states authority to allocate water rights) prevent states (like the State of Washington in the *PUD* case) from regulating stream flow. The Court went on to address the meaning of these provisions and found that while "[s]ections 101(g) and 510(2) preserve the authority of each State to allocate water quantity as between users; they do not limit the scope of water pollution controls that may be imposed on users who have obtained, pursuant to state law, a water allocation." *Id.* The Court cited to its decision in *California v. FERC*, 495 U.S. 490, 498 (1990), construing an analogous provision of the Federal Power Act, where the Court explained that "minimum stream flow requirements neither reflect nor establish 'proprietary rights'" to water. *Id.*

In reaching its holding that minimum stream flow requirements necessary to protect state water quality standards may be required under the CWA, the Court also relied on the legislative history relating to amendments to the CWA that included section 510(2). That legislative history stated as follows:

> "Legitimate water quality measures authorized by this act may at times have some effect on the method of water usage. WQS and their upgrading are legitimate and necessary under this act. The requirements [of the Act] may incidentally affect individual water rights . . . . It is not the purpose of this amendment to prohibit those incidental effects. It is the purpose of this amendment to [e]nsure that State allocation systems are not subverted, and that effects on individual rights, if any, are prompted by legitimate and necessary water quality considerations."

(Legislative History of the CWA of 1977, Ser. No. 95-14, p. 532 (1978))

The implicit nature and necessity of particular flow regimes to protect designated uses and meet antidegradation requirements is fully consistent with the Supreme Court's reasoning and findings in both PUD and S.D. Warren. Specifically, in PUD, the Court agreed that the State of Washington had authority to impose minimum flow conditions on a FERC-licensed project through Section 401 of the CWA to protect designated uses and comply with the State's anti-degradation policy. Despite the fact that the State in that instance did not have specific flow criteria, the State had determined that the project and license at issue and as proposed would not comply with one of the water's designated uses for Class AA waters (fish rearing, spawning, and harvesting). The Court held that CWA section 401 certifications may include conditions to ensure compliance with not only criteria, but also designated uses and antidegradation requirements. The S.D. Warren case likewise upheld the State of Maine's 401 certification requiring minimum flows to protect the designated fishing and recreational uses of an affected water body for which Maine did not have an explicit flow water quality standard.

Nevertheless, the fact that existing WQSs (e.g., designated uses and antidegradation requirements) may already implicitly require maintenance of minimum and/or maximum flows, such WQS have not always proved sufficient to ensure protection of such necessary flow regimes. Adoption of explicit narrative criteria addressing flow and hydrologic conditions will help to ensure a clear understanding of the inextricable link between water quality and water quantity, and ensure that consideration of flow and water quantity is applied through various CWA programs (e.g., CWA section 401 certifications, CWA section and CWA section 402 and 404 NPDES permitting).

8 Appendix B: Overview of the Clean Water Act and Water Quality Standards

In 1972, with the objective of protecting lakes, rivers, streams, estuaries, wetlands, coastal waters, the ocean and more, the U.S. Congress enacted the Clean Water Act (CWA) (officially the Federal Water Pollution Control Act). The overall objective of the CWA is *to "restore and maintain the chemical, physical and biological integrity of the Nation's waters"* (Section 101(a) (emphasis added)). In addition, the CWA establishes as an interim goal *"water quality which provides for the protection and propagation of fish, shellfish and wildlife and provides for recreation in and on the water,"* wherever attainable (Section 101(a)(2)). Section 303(c)(1) of the CWA provides that states must review and revise, as appropriate their water quality standards (WQS) at least once every three years. Section 303(c)(3) provides that EPA is required to review and approve or disapprove such new or revised WQS.

Generally speaking, WQS defines the water quality goals for a water body, or part of a waterbody, by 1) designating the use or uses of the water, 2) setting criteria sufficient to protect those designated uses, and 3) preserving water quality that exceeds the level necessary to protect those uses, as well as existing uses through antidegradation provisions. See generally CWA section 303 and 40 CFR part 131. States adopt WQS to protect public health or welfare, enhance the quality of water, and serve the purposes of the CWA. See id. WQS serve as the regulatory basis for establishing water quality-based treatment controls and strategies, such as National Pollution Discharge Elimination System (NPDES) permits and Total Maximum Daily Loads (TMDLs).

8.1 Designated Uses and Existing Uses

Designated uses are those uses specified in state WQS regulations for each water body or segment regardless of whether or not those uses are actually being attained. The designated uses of a water body are a state's expression of the desired ambient condition and management objectives of a waterbody, such as supporting aquatic life and human activities, including recreation, fishing, shellfish harvesting, and public water supply. Water quality criteria are then adopted to protect the designated uses. The focus of this document is on aquatic life uses. See generally 40 CFR section 131.10.

Existing uses (defined at 40 CFR section 131.3(e)) are uses that have been "actually attained" in a water body on or after November 28, 1975. Existing uses are known to have been "actually attained" when both the use *and* the water quality necessary to support that use have been achieved (1994 WQS Handbook). Determining existing uses that have been actually attained in a water body is typically done on a site-specific basis and may involve evaluating data on the following:

- Historical/current water quality.
- Historical/current biological condition.
- Historical pattern, frequency, and type of use.

Once a use has been designated for a particular water body or segment, that designated use for the water body or segment cannot be removed except under specific conditions. See 40 CFR 131.10(g)(1)-(6). Note however, that if a designated use is an existing use (as defined in 40 CFR 131.3(e)) for a particular water body or segment, it cannot be removed unless a use requiring more stringent criteria is added. See 40 CFR 131.10(g)-(h). However, uses requiring more stringent criteria may always be added because doing so reflects the Congressional goal of further improvement of water quality.

Box B-1: Supreme Court recognizes water quantity as necessary for designated uses

"Petitioners also assert more generally that the CWA is only concerned with water 'quality,' and does not allow the regulation of water 'quantity.' This is an artificial distinction. In many cases, water quantity is closely related to water quality; a sufficient lowering of the water quantity in a body of water could destroy all of its designated uses, be it for drinking water, recreation, navigation or, as here, as a fishery."

-Public Utility District No. 1 of Jefferson County, et al. v. Washington Department of Ecology (PUD), 511 U.S. 700, 719-21 (1994).

8.2 Water Quality Criteria

Water quality criteria are constituent concentrations, levels, or narrative statements representing a quality of water that supports a particular use, such as propagation of fish and wildlife, recreation, and public water supply. 40 CFR section 131.3(b).

EPA develops recommendations for many water quality criteria under the authority of the CWA Section 304(a).[2] See 40 CFR section 131.11(b)(1). Consistent with EPA's WQS regulation at 40 CFR section 131.11, criteria that states adopt into their standards must meet the following

[2] EPA notes that CWA section 304(a)(2) is distinct from CWA section 304(a)(1), which authorizes EPA to "develop and publish … criteria for water quality accurately reflecting the latest scientific knowledge (A) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, esthetics, and recreation which may be expected from the presence of pollutants in any body of water, including ground water; (B) on the concentration and dispersal of pollutants, or their byproducts,

requirements:

- Be based on a sound scientific rationale and,
- Include parameters (e.g., acceptable concentrations) that are sufficient to support protection of the particular water body's designated uses, including the most sensitive use.

States may adopt the recommended criteria that EPA publishes into their WQS, modify EPA's criteria to reflect site-specific conditions, or use other scientifically defensible methods. According to EPA's regulations at 40 CFR section 131.11(b)(2), states should establish narrative criteria or criteria based upon biomonitoring methods where numerical criteria cannot be established or to supplement numerical criteria.

8.3 Antidegradation

Antidegradation is an integral component of a comprehensive approach to protect and maintain water quality. Each state must develop and adopt a statewide antidegradation policy that ensures the maintenance and protection of existing instream water uses and the level of water quality necessary to protect those existing uses. See 40 CFR 131.12. and identify procedures for its implementation. The state antidegradation policy and implementation procedures must be consistent with 40 CFR section 131.12. States may adopt antidegradation statements more protective than the 40 CFR section 131.12, as such statements would be "consistent with" 131.12.

8.4 Using Narrative Criteria

As mentioned above, EPA's regulations at 40 CFR section 131.11, specifically 131.11(b)(2), allow states to adopt narrative criteria or criteria based upon biomonitoring methods where numerical criteria cannot be established or to supplement numeric criteria. Narrative criteria are statements that describe the desired water quality goal, such as: "*No toxics in toxic amounts*". To supplement numeric criteria, states have also adopted narrative criteria to protect designated uses. (For example, the narrative which supports balanced and indigenous flora and fauna can result in numeric targets for nitrogen or phosphorus TMDLs.) Narrative criteria can be the basis for limiting pollutants in permitted discharges where a specific pollutant in the discharge can be identified as causing or contributing to an excursion above WQS but

---

through biological, physical, and chemical processes; and (C) on the effects of pollutants on biological community diversity, productivity, and stability, including information on the factors affecting rates of eutrophication and rates of organic and inorganic sedimentation for varying types of receiving waters."

there are no numeric criteria in place to address the pollutants, or where an excursion cannot be traced to a particular pollutant. See generally 40 CFR section 122.44(d). States may include a procedure to translate narrative criteria to facilitate developing NPDES permit limits and TMDLs in their WQS. See, e.g., 40 CFR section 122.44(d)(1)(vi)(A).

"Narrative water quality criteria have the same force of law as other water quality criteria, and NPDES permits must contain effluent limits necessary to attain and maintain all applicable water quality criteria including narrative criteria." National Pollutant Discharge Elimination System; Surface Water Toxics Control Program, 54 Fed Reg. 23868, 23875 (June 2, 1989).

9 Appendix C: Developing Narrative Criteria for Protection of Hydrologic Conditions

Existing state and tribal narrative criteria may provide useful examples for those states interested in developing or revising hydrology-related criteria. Developing narrative criteria for hydrologic condition can provide the basis for more comprehensive state water quality management to protect aquatic life uses. The goals and provisions of the CWA and EPA's implementing regulations make it clear that states are not limited to adopting chemical specific criteria, but are permitted to adopt criteria, narrative and/or numeric, which address physical and biological stressors to ensure use protection (cite Letter, US EPA Wilcher to US FERC Cashell, January 18, 1991).

9.1 Examples from States and Tribes

Some states and tribes have adopted explicit narrative hydrologic criteria in their WQS that are applicable to all waterbodies of each state (though some have multiple by class, see VT). As of 2012, eleven states had adopted hydrologic (i.e., flow) criteria in their WQS: NH, RI, VT, NY, VA, KY, TN, LA, MO, and OR, while one of California's Regional Water Resources Control Boards (5A: San Francisco Bay/Sacramento-San Joaquin Delta Estuary) had various flow-related inclusions (specifically flow rate) in their WQS (termed "Water Quality Objectives" within Regional Plans). As of 2012, six tribes with TAS for WQS have adopted explicit narrative criteria for flow in their WQS (though in addition to these six tribes, many have wetland criteria for hydrologic conditions). No territories have yet adopted such criteria in their WQS. Most of these narrative flow criteria are written in general terms. Table 1 briefly details the primary language of some of these state and tribal flow/hydrological condition criteria (for the full text of the criteria, please see the EPA website for state and tribal links to the most up to date information: http://water.epa.gov/scitech/swguidance/standards/wqslibrary/index.cfm). Key terms have been bolded for emphasis in the following discussion. More complete examples from New Hampshire and Rhode Island narrative flow criteria are as follows:

- "*Unless flows are caused by naturally occurring conditions, surface water quantity shall be maintained at levels adequate to protect existing and designated uses*" (New Hampshire Code of Administrative Rules Env-Wq 1703.01 (d)).
- "*General Criteria - The following minimum criteria are applicable to all waters of the State, unless criteria specified for individual classes are more stringent:... (h). For activities that will likely cause or contribute to flow alterations, streamflow conditions must be adequate to support existing and designated uses*" (Rhode Island Department of Environmental Management Water Quality Regulations, (2010) Rule 8(D)(1)(h)).

Table 1: Narrative language in WQS of select states and tribes relating to hydrologic criteria

(full version in Appendix X)

State/Tribe	Terms in WQS
NH	"**surface water quantity** shall be maintained at levels adequate to protect **existing and designated uses**"
RI	"**quantity** for protection of… **fish and wildlife**…adequate to protect **designated uses**" "For activities that will likely cause or contribute to flow alterations, streamflow conditions must be adequate to support **existing and designated uses.**"
VT	Class A(1)- Changes from **natural flow regime** shall not cause the natural flow regime to be diminished, in aggregate, by more than 5% 7Q10 at any time; Class B WMT 1 Waters - Changes from the **natural flow regime**, in aggregate, shall not result in **natural flows** being diminished by more than a minimal amount provided that **all uses** are fully supported; and when flows are equal to or less than 7Q10, by not more than 5% of 7Q10. Class A(2) Waters and Class B Waters other than WMT1 - Any change from the **natural flow regime** shall provide for maintenance of flow characteristics that ensure the **full support of uses** and comply with the applicable water quality criteria.
NY	For both Class N fresh surface waters and Class AA(S) fresh surface waters … "There shall be **no alteration to flow** that will impair the waters for their **best usages**."
VA	"**Man-made alterations in stream flow** shall not contravene designated uses including protection of the propagation and growth of **aquatic life**."
KY	"Aquatic Life. (1) Warm water aquatic habitat. The following parameters and associated criteria shall apply for the protection of productive warm water aquatic communities, fowl, animal wildlife, arboreous growth, agricultural, and industrial uses:...(c) **Flow** shall not be altered to a degree which will adversely affect the **aquatic community**."
TN	Criteria for Water Uses "(3) Fish and Aquatic Life (n) Habitat- The quality of stream habitat shall provide for the development of a **diverse aquatic community** that meets regionally-based biological integrity goals. Types of habitat loss include, but are not limited to: channel and substrate alterations… stream **flow** changes…. For wadeable streams, the instream habitat within each subecoregion shall be generally similar to that found at **reference streams**. However, streams shall not be assessed as impacted by habitat loss if it has been demonstrated that the biological integrity goal has been met. (o) Flow- Stream or other waterbody **flows shall support the fish and aquatic life criteria**." "(4) Recreational. (m) Flow- Stream **flows** shall support **recreational**

	uses.”
MO	“Waters shall be free from physical, chemical, or hydrologic changes that would impair the natural biological community.”
Seminole Tribe of FL	“Class 2-A waters shall be free from activities...that …Impair the **biological community** as it naturally occurs… due to …**hydrologic changes**”
Mole Lake Band of the Lake Superior Tribe of Chippewa Indians	“prohibited…human induced changes to … area **hydrology** that alter **natural ambient conditions**…such as…flow, stage…. Natural daily fluctuations of flow, stage… shall be maintained.”
Bad River Band of the Lake Superior Tribe of Chippewa Indians	“Water quantity and quality that may limit the growth and propagation of, or otherwise cause or contribute to an adverse effect to wild rice, wildlife, and other flora and fauna of cultural importance to the Tribe shall be prohibited.” “**Natural hydrological conditions** supportive of the **natural biological community**, including all flora and fauna, and physical characteristics naturally present in the waterbody shall be protected to prevent any adverse effects.” “Pollutants or human-induced changes to waters, the sediments of waters, or area hydrology that results in changes to the natural biological communities and wildlife habitat shall be prohibited. The migration of fish and other aquatic biota normally present shall not be hindered. Natural daily and seasonal fluctuations of flow (including naturally occurring seiche), level, stage, dissolved oxygen, pH, and temperature shall be maintained.”

As Table 1 illustrates, narrative hydrologic criteria for aquatic life uses may be written in various ways, but there are two key aspects that each one addresses. The first is a description of the object of protection or protection goal, which may be an explicit reference to the aquatic life uses or general language that addresses protection of the suite of designated and/or existing uses. The second is the language describing the hydrologic condition to be maintained in order to protect the aquatic life uses. Narrative criteria are generally adopted to apply to all surfaces waters.[3] For instance, some states (e.g., Vermont) have developed narrative criteria for each

[3] Most states and tribes have narrative criteria that apply to all surface waters in their state or tribal lands regardless of the designated uses of the waters. For example, chemical mixtures and floatable debris are, commonly addressed with a single narrative criterion that applies to all surface waters , utilizing language such as “no toxics in toxic amounts”, “no objectionable deposits” and, “surface waters shall be virtually free from floating non-petroleum oils of vegetable or animal origin, as well as petroleum-derived oils”.

water body classification, along with more detail to aid in implementation.

The criteria in Table 1 either encompass aquatic life uses in general or specifically refer to aquatic life designated use protection. The balance between generality (e.g., to protect designated uses) and detail (e.g., specific ecological endpoints to protect such as significant life stages) may be important to facilitate implementation. Such language may suggest the best indicators for attainment of the WQS and assist with consistency throughout application in other programs such as monitoring and assessment, providing more clarity in objectives.

While the object of protection is aquatic life (the valued assessment endpoint), key elements of the natural hydrograph (i.e., flow metrics) are the most easily measured endpoint, indicating the protection of the use. As previously mentioned, in monitoring and assessment, EPA recognizes flow or hydrologic conditions as recommended "core" water quality indicator for general designated uses for aquatic life, wildlife or other uses (e.g., recreation and drinking water) (CALM Guidance, U.S. EPA 2002). Flow indicators could include biological indices, risk assessment levels and other measures to provide consistently practical and cost-effective assessments statewide (CALM Guidance, U.S. EPA 2002). Using relationships between ecological indicators and hydrologic metrics will facilitate quantification of narrative hydrologic criteria and will be discussed in the following chapters.

Box C-1: Minimum Flow, a Note of Caution

The most current scientific research indicates environmental flow standards of any kind should support the natural flow regime, and that a standard based on minimum flow by itself will, most likely, not maintain ecosystem integrity (Poff et al. 1997, Bunn and Arthington 2002, Annear et al. 2004), in part because minimum flows do not address the seasonal and interannual variability of the natural flow regime. To maintain ecosystem health, native aquatic communities need critical levels of flow magnitude, duration, and timing to be met and a minimum flow value is not sufficient to maintain the health of a balanced community (Stalnaker 1990, Hill et al. 1991, Postel and Richter 2003). Thus, narrative hydrologic criteria should consider more than maintenance of a minimum stream flow.

The best approaches for ecological flow criteria in general not only identify flow needs but also the natural timing and duration of the delivery of those flows to support ecosystem needs (Poff et al. 2010). While a 7Q10 design flow has a magnitude and duration, it is not intended to serve as a protective hydrologic criteria; its purpose is for developing waste load allocations to ensure water quality criteria are met.

The natural seasonal fluctuation of waters in rivers and streams is critical to maintenance of aquatic ecosystems because aquatic biota is adapted to these fluctuations. The Instream Flow Council (IFC) recommends developing standards that incorporate natural patterns of intra- and inter-annual variability in a manner that maintains and/or restores riverine form and function, to best maintain ecological integrity (Annear et al. 2004).

10Appendix D: Hydrologic Considerations in other CWA programs

States often use translation procedures to implement narrative criteria in managing objectives and targets in CWA programs such as CWA section 401 certifications, TMDL establishment and NPDES permitting (for example, the narrative "no toxics in toxic amounts can result in an NPDES effluent limit for ammonia). The following sub-sections provide brief descriptions of hydrologic considerations for these programs, and where feasible, references and examples of narrative criteria translations to assist states and tribes with their implementation efforts.

10.1.1 Monitoring and Assessment

A state ensures that each water quality standard adopted by a state is met by monitoring to assess attainment status, reporting on attainment and identifying impaired waters, and implementing controls necessary for attainment. EPA's 2002, Consolidated Assessment and Listing Methodology (CALM) guidance recommends that one of the first steps a state undertakes in designing a monitoring framework for water quality is identification of the appropriate indicators and their endpoints (Chapter 10 of "CALM Guidance"). The Intergovernmental Task Force on Monitoring Water Quality (1995) and the EPA recognize flow regime as a recommended "core" water quality indicator for general designated uses (endpoints) in the following categories: aquatic life and wildlife, recreation and drinking water. Flow regime metrics are found to be reliable physical habitat assessment indicators for determining aquatic life use support ("CALM", 2002). Since altered hydrology is often an underlying cause of impairment for habitat, biology, and other physical and chemical-specific parameters that affect aquatic life use attainment, many effective state monitoring programs include monitoring for flow, in addition to other parameters.

Once core and supplemental monitoring indicators are established for a WQS, a state should then describe how it assesses attainment with the standard either as part of the WQS, in other implementing state regulations, policies, or procedures, or in a state's assessment and listing methodology.

A state's assessment and listing methodology outlines the decision process used for determining whether particular designated uses are being met and, assigns those segments to a reporting category in the state's Integrated Report submittal to EPA (to meet reporting requirements under CWA sections 305(b)) and 303(d)).[4] For example, Vermont's assessment methodology refers to the State's hydrologic narrative criteria (see Appendix X for full text) in

[4] EPA's regulations at 40 CFR section 130.7(b)(6)(i-iv) require states to provide documentation

describing the "altered waters" category especially for hydrologic alteration. The State's methodology also qualitatively describes methods consistent with the criteria to assess whether or not the waterbody is meeting WQS (http://www.vtwaterquality.org/mapp/docs/mp_assessmethod.pdf). A more technical document describes the procedures to determine streamflows for issuing permits and CWA section 401 certifications that meet WQS (http://www.vtwaterquality.org/rivers/docs/rv_flowprocedure.pdf). An overview of the streamflow program is available (http://www.vtwaterquality.org/rivers/htm/rv_flowprotection.htm).

When designing a water quality monitoring framework one of the first steps a state may undertake is identification of the appropriate indicators and their endpoints, driven by a state's WQS (Chapter 10 of Assessment and Listing Methodology- Toward a Compendium of Best Practices, i.e., "CALM Guidance", U.S. EPA, 2002). The Intergovernmental Task Force on Monitoring Water Quality (1995) and the EPA recognize flow as a recommended "core" water quality indicator for general designated uses. The EPA recommends monitoring flow as a method for determining whether a waterbody segment supports aquatic life, wildlife, recreation, and drinking water designated uses. In addition, flow regime metrics are reliable among parameters used in physical habitat assessment- an important indicator for aquatic life use support determinations that may include many indicators of hydrologic alteration, such as bank scour or destabilization. Other physical habitat indicator data include natural channel morphology, substrate composition, bank/riparian structure, and riparian vegetation (Chapter 8 of CALM Guidance Consolidated U.S. EPA, 2002).

Chapter 6 of this document deals with identifying and quantifying the degree of alteration of hydrologic condition, which may assist monitoring and assessment activities.

10.1.2 Identifying Impaired Waters and Developing TMDLs for Restoration

After assessing whether or not the designated uses are being met for a particular waterbody, the next step involves the reporting of those waterbody segments where an applicable WQS is not met and a TMDL is needed-- known as the "303(d) list" of impaired waters. The 303(d) impaired waters listing process is a biennial process where states evaluate all "existing and readily available data", describe their methodology for determining the list, and provide opportunities for public comment on the proposed list of waters. The 303(d) list provides the public with available data and determinations that can serve as a "catalyst" signaling the need for additional pollution control actions and informing future water quality management decisions.

---

that supports the state's determination to list or not list its segments on the 303(d) impaired waters list (see also 130.7(b)(1) and 130.7(b)(2)).

While CWA section 303(d) and its implementing regulations do not require states to list impaired waters solely due to pollution (e.g., altered hydrology or flow), quantity of flow and variation in flow regimes are important factors in transporting other pollutants (e.g., sediment, pathogens, metals) that violate water quality standards, and hence, flow is usually considered when listing waters as it pertains to pollutants. Additionally, many impaired waters are listed for biological impairments related to not only the suite of pollutants in stormwater-source discharges, but also from the high flows and velocity resulting from stormwater runoff. States are required to list for biological impairments unless they can demonstrate that the impairment is due to a non-pollutant (e.g., flow). If the impairment is due to a non-pollutant, EPA's integrated reporting guidance for state 303(d) listing decisions and 305(b) water quality reporting ("IRG" 2005), recommends states place that waterbody in category 4c—impaired due to pollution, but not requiring a TMDL. The transparency in the integrated reporting categories ensures these waters remain in the public's eye and are not simply ignored. The listing of impaired waters is one way to acknowledge the important role that flow and hydrology have in contributing to waterbody impairments. For those waters identified as impaired due to pollution, as identified in IR category 4c, EPA believes states should continue to monitor these waters and institute actions to begin the task of returning the waterbodies to full attainment of WQS. Figure 1 illustrates how Vermont, identifies flow-altered waters in category 4c of their Integrated Report. Vermont also describes the status of current management or control activities for each of these waters for enhanced public transparency (See Figure 1 and Box 5-1).

Figure 8: Vermont's Integrated Report Categorization of 4c Rivers and Streams

Part F. Waters appearing below are altered by flow regulation. These are priority waters for management action.

Waterbody ID	Segment Name/ Description	Use(s) Impacted	Surface Water Quality Problem	Current Status/Management or Control Activity	Projected WQS Compliance Year
VT01-03	BASIN BROOK	ALS	POSSIBLE LACK OF MINIMUM FLOW BELOW WATER SUPPLY WITHDRAWAL POINT (THREAT)	WSID #5017 - NORTH BENNINGTON WATER DEPT; SERVES AS BACK UP SUPPLY SOURCE TO GRAVEL WELL FIELD	
	BOLLES BROOK/ROARING BRANCH, INTAKE TO CITY STREAM CONFLUENCE	ALS	POSSIBLE LACK OF MINIMUM FLOW BELOW WATER SUPPLY WITHDRAWAL POINT (THREAT)	WSID #5016 - BENNINGTON WATER DEPT; ASSESSMENT OF WATER WITHDRAWAL IMPACT DIFFICULT GIVEN LOW PRODUCTIVITY & LOW pH EFFECT	
VT03-04	LEICESTER RIVER, FROM DAM ON LAKE DUNMORE TO 1.0 MILE DOWNSTREAM	ALL USES	ARTIFICIAL FLOW REGULATION & CONDITION BY HYDRO	UNLICENSED FACILITY	2017
	LEICESTER RIVER, FROM SALISBURY DAM TO 5 MILES DOWNSTREAM	ALL USES	ARTIFICIAL FLOW REGULATION & CONDITION BY HYDRO	UNLICENSED FACILITY	2017
		ALS	POSSIBLE DOWNSTREAM FISH PASSAGE PROBLEM AT DAM (THREAT)	UNLICENSED FACILITY	2017
VT03-04L05	LAKE DUNMORE (Salisbury)	ALS	WATER LEVEL MGMT BY HYDRO ALTERS AQUATIC BIOTA	LAKE ASSOC. HAS WATER LEVEL AGREEMENT W/CVPS	2017
VT03-05	OTTER CREEK, 0.1 MILES BELOW PROCTOR DAM	AES	ARTIFICIAL DEWATERING OF LARGE WATERFALL BY HYDRO	FERC LICENSE EXPIRES IN 2012	2012
VT03-06	FURNACE BROOK		LACK OF MINIMUM FLOW BELOW WATER SUPPLY WITHDRAWL POINT	BACKUP WATER SUPPLY FOR PROCTOR	
	KILN BROOK	ALS	LACK OF MINIMUM FLOW BELOW WATER SUPPLY WITHDRAWAL POINT (THREAT)	WSID #5228 - PROCTOR WATER DEPT; MUNICIPALITY STARTED MONITORING STREAMFLOWS IN 2007 IN COOP WITH ANR	
VT03-12	SOUTH BRANCH, MIDDLEBURY RIVER (1.4 MILES)	ALS	ARTIFICIAL FLOW CONDITION, INSUFFICIENT FLOW BELOW SNOW BOWL SNOWMAKING WATER WITHDRAWAL	PARTIAL SUPPORT 1.4 MI (6.0 MI TOTAL LENGTH)	

2012 Part F List of Waters - Final *Page 1 of 10*

Source: Vermont 2012 Priority Waters List
http://www.vtwaterquality.org/mapp/docs/mp_2012_priority_waters_lists.pdf

Box D-1: Vermont Addresses Hydrologically Altered Waters

Vermont was the first state to adopt hydrologic condition criteria for its water bodies (See Appendix X for full text). Although hydrologic alteration is listed under integrated reporting category 4c (not requiring a TMDL), Vermont does address the non-compliance with WQS through the Vermont Priority Waters List. This list includes waters assessed as “altered” using their assessment methodology (http://www.vtwaterquality.org/mapp/docs/mp_assessmethod.pdf). Part F lists waters that do not support one or more designated uses due to alteration by flow regulation (primarily from hydroelectric facilities, other dam operations, or industrial or municipal or snowmaking water withdrawals). This list includes a description of the problem, current status or control activity, and the projected year the water body segment will come into compliance with WQS. See Figure 8.

Once on the 303(d) list, states must also prioritize these waterbodies for TMDL development. Where no pollutant is identified as causing an exceedance of water quality standards, EPA does not believe the CWA requires a TMDL to be established. In some cases, the pollution is caused by the presence of a pollutant, and a TMDL is required. In these instances, the contributing effect of pollution is to be accounted for and dealt with in the TMDL by calculating and allocating the total pollutant load in light of, among other things, seasonal variations in flow (CFR 130.2 and CFR 130.7).

Flow is also an important factor in the development of more traditional, pollutant-specific TMDLs, when calculating the greatest amount of loading that a waterbody can receive without violating water quality standards. For example, flow frequently combines with temperature and other environmental factors to create critical conditions which cause violations of water quality standards, and must be considered during TMDL development, first, to identify conditions under which water quality monitoring is conducted for attainment purposes (e.g., low flow, summer-time temperatures), and second, to help identify actions needed to meet water quality standards. Additionally, flow is one of the most important parameters in water quality models used to establish the cause-and-effect-relationship between the numeric TMDL target and the identified pollutant sources.

While the TMDL program does not have a separate guidance document on addressing impairments from flow, several TMDL technical documents exist that include a discussion of flow in methods and models to develop loadings and load and wasteload allocations, and also of TMDL implementation. These include EPA's document on developing TMDLs based on the load duration curve approach, and EPA's 1999 Protocol for developing sediment TMDLs since sediment TMDLs are especially likely to be influenced by flow regimes (http://www.epa.gov/owow/tmdl/sediment/pdf/sediment.pdf).

10.1.3 CWA Section 401 Certifications

The CWA Section 401 certification process can be a powerful tool for protecting aquatic resources. The CWA gives the states the authority to grant, condition, or deny a federal permit or licensing action (CWA section 401(a)(1)). Before issuing a CWA section 401 certification, the state should ensure that the permitted or licensed activity will be consistent with the state's water quality standards and any other appropriate requirement of state law including provisions relating to hydrologic conditions, which may or may not be included in the state's WQS. This could include provisions relating to hydrologic condition, which may or may not be explicitly included in the state's water quality standards. A narrative criterion for hydrologic condition can provide states a basis to better define the conditions of a federal permit or license and provide more control over actions that could have significant effects on aquatic life designated uses through altered hydrologic condition. See two examples in Box D-3 .

Listing for impairment can have implications in the 401 certification process. 4C listings are a way to recognize flow-related impairments in hydropower projects, until appropriate operating conditions can be negotiated within the Federal Energy Regulatory Commission (FERC) permitting process and the state's CWA section 401water quality certification authority.

Box D-3: 401 Certifications, Sufficient Flow and Water Quality Standards

South Carolina Board of Health and Environmental Control Denied Certification
"The Board finds that the WQ Certification does not provide sufficient flow to protect classified uses, the endangered shortnose sturgeon and adequate downstream flow…to provide reasonable assurance… that WQS will be met."

PUD No. 1 of Jefferson County, et al. v. Washington Department of Ecology, 511 U.S. 700, 719-21 (1994) addressed the question of whether flow may be linked to WQS and whether a state may include specific flow requirements in a CWA section 401 certification. Challenge related to State of Washington's inclusion of minimum flow requirements in a 401 certification for a FERC relicensing of hydropower plant. The Court held that the State of Washington was authorized to require the plant to maintain certain stream flows as a condition of a Section 401 certification. It should be noted that in this case, the State of Washington did not have explicit narrative or numeric criteria related to flow, but that the certification was conditioned to address flow in order to protect the designated use and meet antidegradation requirements.

-*Public Utility District No. 1 of Jefferson County, et al. v. Washington Department of Ecology (PUD)*, 511 U.S. 700, 719-21 (1994).

10.1.4 CWA Section 404 Permits

CWA section 404 dredge-and-fill permitted projects may include removal of the conditions necessary for survival of lotic species (those species that are dependent upon flowing water for survival) and result in the inability to meet WQS. These projects may include the construction of new water withdrawal or storage systems, expansion of existing water withdrawal or storage systems, and construction of projects that impact hydrology such as drinking water reservoirs, fishing reservoirs or amenity ponds. These 404 projects would be subject to Section 401 certification including an antidegradation review. Therefore, where states are not authorized to administer the CWA section 404 program, state review and certification under CWA section 401 of such proposed permits should involve a careful review of whether the project would adversely affect conditions necessary for survival of lotic species, among other flow- or hydrologic conditions-related issues. While the focus of antidegradation reviews has often been on compensatory mitigation, Regions and states should fully consider the requirement to avoid and minimize impacts from significant hydrologic alterations as well, with analysis of alternative approaches, designs, or locations for achieving the same objective.

10.1.5 Stormwater Permitting

National Pollutant Discharge Elimination System (NPDES) permits are generally required for stormwater discharges from three sources: municipal separate storm sewer systems (MS4s) identified in EPA's regulations, construction activities that disturb one or more acres, and industrial activities. While most NPDES permits require permittees to implement stormwater management programs, permits may also establish numeric effluent limitations.

The benefits of a surrogate TMDL in a stormwater context are the ease and effectiveness of implementation. Surrogates such as % impervious cover or a flow metric(s) may be more easily monitored and evaluated compared to monitored pollutant(s) over a large area and many outfalls. A state can develop or use existing tools to translate between BMP reduction of flow volume and pollutant load for implemented TMDLs based on a surrogate. Part II of this white paper may provide useful approaches and tools to translate the narrative criterion for use in determining numeric endpoints useful in permitting.

11 Appendix E: An Introduction to Hydrogeomorphological Classification

To adequately define flow standards at a state or regional level that protect natural flow variability, it may be necessary to classify streams hydrogeomorphically. Hydrogeomorphic stream classification captures the physical, climactic and flow characteristics affecting a stream and supports classification efforts on a regional basis. Hydrologic stream classification characterizes similarities among rivers based on a range of hydrologic flow metrics, stream type and source that vary across the landscape. Hydrologic flow metrics are derived from stream gauge data (daily, monthly, and annual stream flows) and are used to describe the flow regime (extreme events, seasonal patterning, timing, frequency, and duration of flows, etc.). Comparing relevant ecological data to the hydrologic metrics may reveal relationships between flow alteration and ecological responses; trends concerning relevant ecological endpoints can be identified by hydrogeomorphic river type (Olden et al. 2011). When attempting to classify streams in a regional context, the incorporation the physical environmental characteristics can provide a richer context for interpreting ecological responses (Poff et al. 2010). Geomorphology, especially in terms of gradient, impacts flow directly and its impact will be more significant in topographically variable regions.

The physical setting of a river controls the flow regime, riverine habitats and biota (Poff et al. 2010). Streams that have similar flow characteristics may behave differently under different geomorphic settings. Classifying stream types by physical characteristics, such as grain size of channel bed, slope and/or channel morphology will further describe the natural setting and will strengthen the development of relationships between flow alteration and ecological response that reflect both direct and indirect effects of hydrologic alteration on ecosystem structure and function (Poff et al. 2011). Using nested hierarchical classification systems recognizes that large-scale controls at the basin level affect smaller-scale features at the catchment level (Thompson et al. 2001). Having these classification systems in place will reduce management decisions and efforts for developing flow standards. Hydrogeomorphic classification systems can also set an organization for developing reference conditions at the local level (Thompson et al 2001).

Hydrogeomorphic classification can be used to extend insights gained from observed trends in well-gauged rivers to ungauged or minimally-gauged streams. Regression analysis can be used to relate physical basin characteristics to hydrologic metrics used to describe flow regime, to extrapolate data to ungauged areas (Olden et al. 2011). The natural variability within riverine systems can be expressed by assigning streams or river segments to a particular hydrogeomorphic type and data from a limited number of stream or river segments can be used to determine stream types and flow data for all stream or river segments within a region or state. Considering the physical characteristics of a basin when extrapolating flow metrics allows models to be used with greater confidence (Olden et al. 2011). Regions, states and localities are making efforts towards protecting environmental flows, but can be stymied by the costs and efforts needed to develop standards and flow-ecology relationships for large land areas; robust stratification schemes are critical for success (Sanborn and Bledsoe 2006).

Many methods have been tested and used to predict streamflow classification based on upstream physical characteristics (surficial geology, slope, drainage area, soil type) and climate data (precipitation, temperature, evapotranspiration) (Olden et al. 2011). Numerous local, state and regional hydrogeomorphic classification regimes have been developed and are in use as effective tools to enhance the development of flow alteration-ecological response relationships. The use of these classification systems facilitates future biomonitoring design and is especially useful for capturing the full range of ecological responses across a gradient of hydrologic alteration for different river types.

11.1 Relevant ecological scales for CWA implementation

The scale of hydrogeomorphic classification must integrate three considerations. First, the integrity of river and stream ecosystems depend on processes at multiple spatial scales, which have been represented as a hierarchical structure (Frissell et al. 1986). Second, CWA is administered spatially around segments of river systems. Third, there are efficiencies in developing an information base from broad ecoregions in the development and administration of WQS/criteria. In combination, these considerations can guide the development of a hydrogeomorphic classification system that represents ecological similarities and distinctions between rivers reflecting their sensitive to hydrologic alteration and is useful for assessing impairment and developing protection or remediation strategies.

11.2 How many classes are necessary?

The number of classes is not an inherent attribute of a region that is discovered through an analytical process. The number of classes in a classification system requires a deliberative assessment of the tradeoff between detail (more classes with less variability in a class), and interpretability (fewer classes with a limited number of distinguishing features). Ultimately, the number of classes requires a decision that Olden et al. 2011 suggest should be based on "objective (statistical) criteria, ecological rationale and/or considering a trade-off between resolution of hydrological variability and complexity (number of classes)." Most hydrologic classifications have less than 20 hydro-classes (Poff 1996; Dettinger and Diaz 2000, Snelder and Biggs 2002; Kennard et al. 2010) depending on the classification area and its application.

The number of hydro-classes in a region should reflect the region's physiographic diversity to the extent that the distribution of community types and their sensitivity to flow alteration is determined by physiography. Regions with diverse climates, geology, and land forms will have more river types; however, classes do not have to represent the full range of statistical variation in streamflow characteristics. Instead, they should target those characteristics that correspond to ecological differences and are likely to be modified (e.g., seasonal patterns of high and low flows, base flow magnitude). Incorporating additional flow characteristics can blur distinctions that are evident when limiting classification to the most ecologically important and management relevant flow characteristics. Gaps in spatial coverage may limit the resolution of classification or create classes with limited number of members and, as a result, poor generalization of flow characteristics for those classes.

Distinct classification schemes can be developed specifically for different objectives. The development models to infer reference flow conditions at ungaged and flow-impaired sites might rely on fine-scale physiographic distinctions between rivers to increase the precision of estimated (modeled) flows. In contrast, definition of groups of sites for analyzing ecological responses to flow alteration will be guided principally by the expectation of similarity in reference communities. A classification system used to administer CWA may be able to collapse some groups developed for hydrologic or ecological analysis if similar criteria are used across different groups. Temporal scale considerations include,

- consistent climatic period for classification,
- identification of potential impacts from climate change (e.g., will reference classes have different flow characteristics or will membership simply shift?) and,
- selection of hydrologic metrics.

11.3 Hydrogeomorphological classification based on the natural (reference) flow regime for gauged and ungauged streams

"*Classification is the placing of objects into predefined groups…It is important to realize that there is no concept of accuracy for an unsupervised classification, the only way of judging the outcome is by its usefulness.*" (Fielding, 2007)

Natural hydrologic variability provides a physical template for freshwater ecosystems (Poff and Ward, 1989). Classification reduces the full range of observed natural hydrologic variability into a limited number of patterns that can be used to group streams facilitating the development and implementation of flow criteria. Assessments of expected biological condition and hydrologic alteration depend on an understanding of unaltered flows patterns.

Before initiating classification, recognize that classification can be used to achieve multiple objectives and the approach must be tailored to specific objectives. For flow criteria, there are four objectives: partition stream segments based on natural hydrologic variability; develop characteristic ecological responses to hydrologic alteration for different stream types; implement consistent flow criteria efficiently; and design monitoring networks.

A general classification framework can be used to achieve these objectives regardless of whether a new classification system is developed or an existing classification system is modified, (Olden et al. 2011). The basic approach has five steps:

1. develop a database of streamflow gages (sites with streamflow records) in association with a broader geospatial database of streams (e.g., NHD);
2. identify "reference/best available" (Stoddard et al., 2006) sites and time periods to represent "natural" streamflow variability;
3. select appropriate streamflow metrics;
4. apply clustering techniques to identify streamflow patterns common to groups of sites; and
5. apply classification techniques to assign sites to groups.

Unaltered streamflow information is necessary develop classes of natural hydrologic variability. In some cases, hydrologic alteration can be assessed directly from a long streamflow record to identify an "unaltered" period. More commonly, ancillary information about the construction of dams, appropriation of water for out-of-stream uses, or land use changes is used to identify locations and time periods that can be used to represent unaltered streamflow. In some regions, streamflow records for reference sites, which have no local anthropogenic alteration of streamflow, may be available. In other regions, it is likely that the best available information will include altered streamflow, which can be useful but should be represented as from the least disturbed sites rather than undisturbed sites (Carlisle et al., 2009).

Even in cases where there is little information for reference sites, best available streamflow information may provide adequate estimates of unaltered conditions for some streamflow metrics. For example, regulated rivers with no effective inter-annual storage or large withdrawals and urban streams may provide adequate estimates of unaltered mean streamflow. Each of such cases must be evaluated to assure that information gained outweighs any added uncertainty.

Simulated streamflow could be used as another source of information for unaltered conditions, but the uncertainty must be understood and should be propagated through the calculation of streamflow metrics. For gaged sites where the effects of river regulation or withdrawals are known, then simulated streamflow is likely to be adequate. Likewise, modeled streamflows could be used to provide streamflow information with a consistent time basis (e.g., 1970-2000). For ungaged sites, however, simulated streamflow is likely to have significant errors particularly for high and low flows. Likewise, re-constructing unaltered streamflow for gaged sites with multiple, complex forms of hydrologic alteration are likely to introduce large errors or biases based on the assumptions used for re-construction.

Streamflow metrics used for clustering and classification are typically derived from daily streamflow values though other types of streamflow potentially could be used. Because of temporal variability in streamflow, relatively long records are needed for reliable estimates of many streamflow metrics (e.g., mean April streamflow, median annual high flow) and especially for metrics representing infrequent but ecologically important conditions (e.g., 10-year low flow). As a general rule, 15 to 20 years has been suggested a minimum length of record for classification (Kennard et al 2010a, Olden et al 2011), but this depends on the metric of interest and regional climate variability. The specific starting and ending years should also be considered as climatic trends or oscillations can bias estimates and lead to apparent differences between sites.
[*The selection of hydrologic and geomorphic metrics is described in a subsequent section but is an important consideration at this point*]

Clustering defines groups of sites with geomorphic and hydrologic similarities based on available information. A variety of techniques are available for clustering sites into groups, which is beyond the scope of this document (see Olden et al. 2011). It is important to recognize that clustering results reflect a number of methodological decisions that are not readily apparent. For example statistical (rather than ecological) weighting of flow characteristics reflects the variance of the metrics used and the redundancy of metrics in terms of the flow characteristic they represent. As well, clustering requires explicit methodological decision including the number of clusters or degree of separation between clusters that will be accepted. These decisions should be clearly explained and used to provide a more useful classification system, rather than casting them in terms of objective – but arbitrary – criteria.

Clustering has limited utility for assigning sites to specific groups. Sites with available information used for clustering are assigned to a group. In some cases, new sites with the same type of information can be assigned to a cluster, but clustering does not provide "decision" rules for assignments. Classification is used to assign sites to a group and can also be used to develop rules for assigning sites to groups based on surrogate information (e.g., physiographic characteristics of a stream basin, land cover, etc.). In most cases, classification groups will not exactly match clusters, but this should not be a major concern since clustering is limited to statistical considerations. Classification can bring in considerations of ecological factors and hydrologic alteration to define more useful groups.

A principal issue for classifications is application to ungauged sites. There are two approaches: either models can estimate values of hydrologic variables used to assign a site to a class or surrogate information available for all sites (e.g., elevation, precipitation, land cover) can be used as the basis for classification. In former case, classification rules are simply applied to the modeled values for a site. The error rates can be evaluated by classifying gaged reference/best available sites based on modeled values for those sites. In the latter case, a separate set of rules must be developed for assigning an ungauged site to a class. The error rates of those rules can be ….

12 Appendix F: Regional Conceptual Models

12.1 Southeastern United States: A Georgia watershed

Landscape context: The landscape topography of a watershed within the Chattahoochee River basin is characterized by three distinct physiographic provinces:the Blue Ridge Mountains, Piedmont region, and Coastal Plain physiographic provinces that extend throughout the southeastern United States. In the Piedmont region of the Chattahoochee River Basin, the regional climate is temperate characterized by hot, humid summers, mild winters, an average of 55 inches of rain per year and an average evapotranspiration rate of 37 inches per year. Streams in the Piedmont are associated with gentle to moderate gradients, riffles and shoals. Much of the Piedmont is heavily urbanized and many impoundments are in place for the provision of reservoirs.

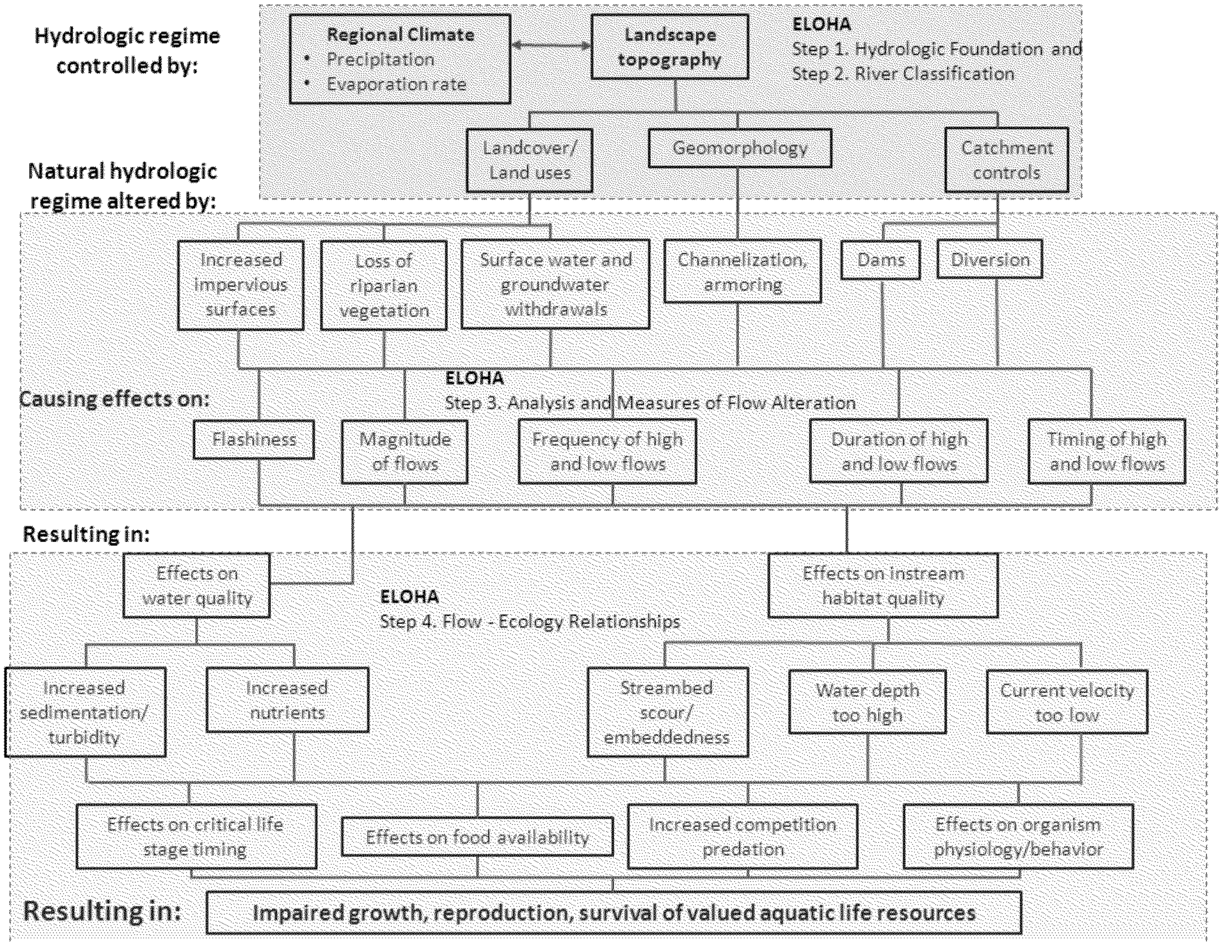


Figure 2. Georgia.

Stressors: Increased impervious surfaces from rapid urbanization and catchment controls have resulted in stream channelization, often in the form of severe entrenchment. These physical alterations have affected the magnitude, frequency and duration of high and low flows and flashiness of streams.

Effects: Flow alteration results in:

- Effects on water quality through increased sedimentation, affecting aquatic organism physiology and behavior.
- Effects on instream habitat quality due to water depths that are too high and velocities that are too low, compared to the natural hydrologic regime. This altered environment affects critical life stage timing, creates increased competition with non-native species, and renders habitat inadequate for native species.

These effects on water quality and instream habitat quality result in: impaired growth, reproduction, and survival of native aquatic life resources.

12.2 Pacific Northwest: A Washington watershed

Landscape context: The Snohomish watershed of western Washington drains to Puget Sound and is characterized by a temperate marine climate with cool wet winters and warm dry summers. Precipitation is not evenly distributed spatially, primarily due to the Cascade Mountain front and temporally due to the seasonality of precipitation. Precipitation ranges from 35 to 180 inches per year, with an average of 87 inches per year. There are traditionally two distinct periods of high monthly flows coinciding with winter precipitation (November through January) and summer snowmelt (May and June).The landscape is characterized by steep mountains, glaciated U-shaped valleys and wide, flat floodplains at lower elevations, near Puget Sound. The Snohomish watershed drains high-elevation areas of the Cascade Mountains; spring and early summer snowmelt strongly influence instream flow and is a strong driver of summer low flow conditions.

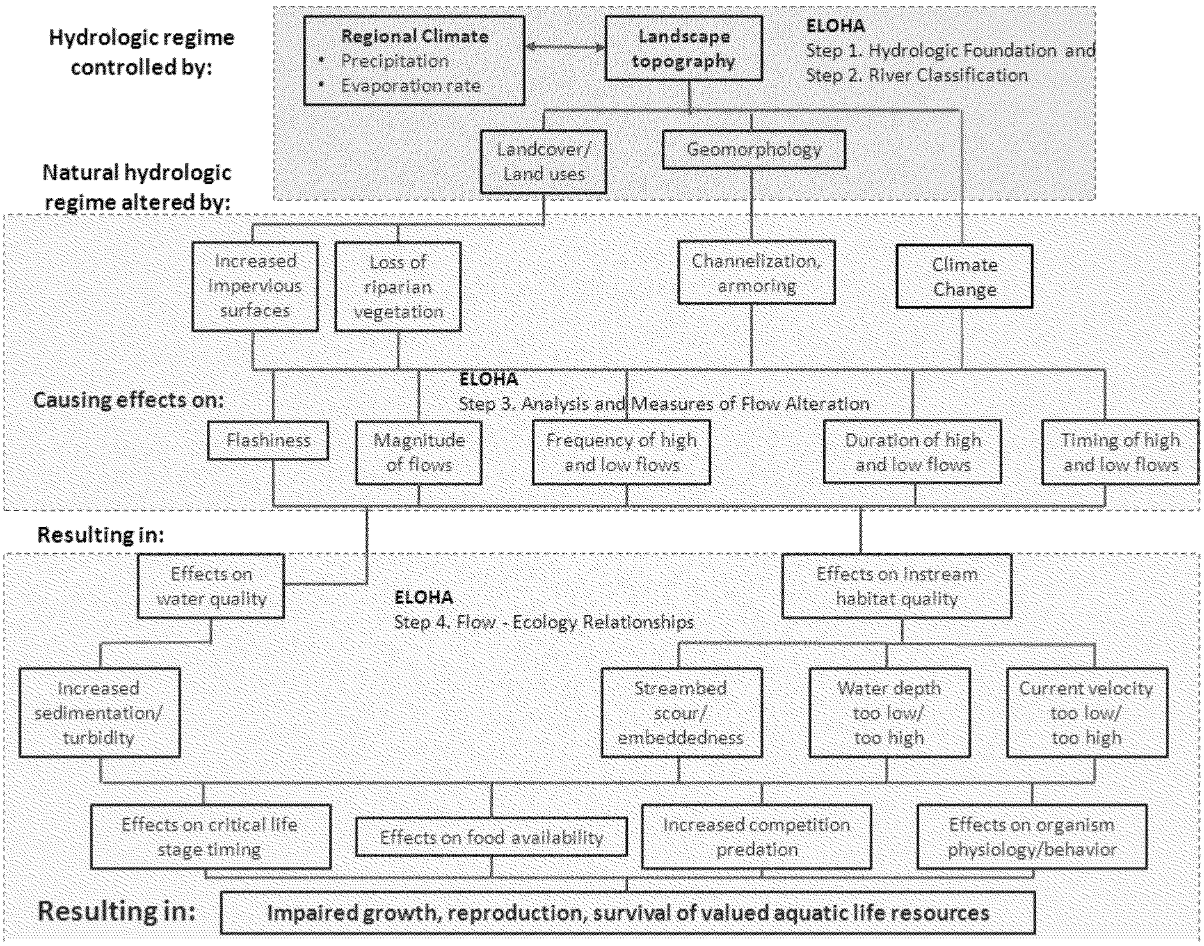


Figure 3. Washington.

Stressors: Most of the high elevation portions of the watershed are in US Forest Service and private forest ownership; the land has been logged historically and currently, at different intensities. There are very few impoundments in the watershed; these exist for drinking water reservoirs. The lowlands of the watershed are urbanized and rural residential development is scattered throughout the floodplain areas. Climate change has altered and is expected to alter the snowpack more severely, thereby impacting magnitude and timing of flows and the form of precipitation.

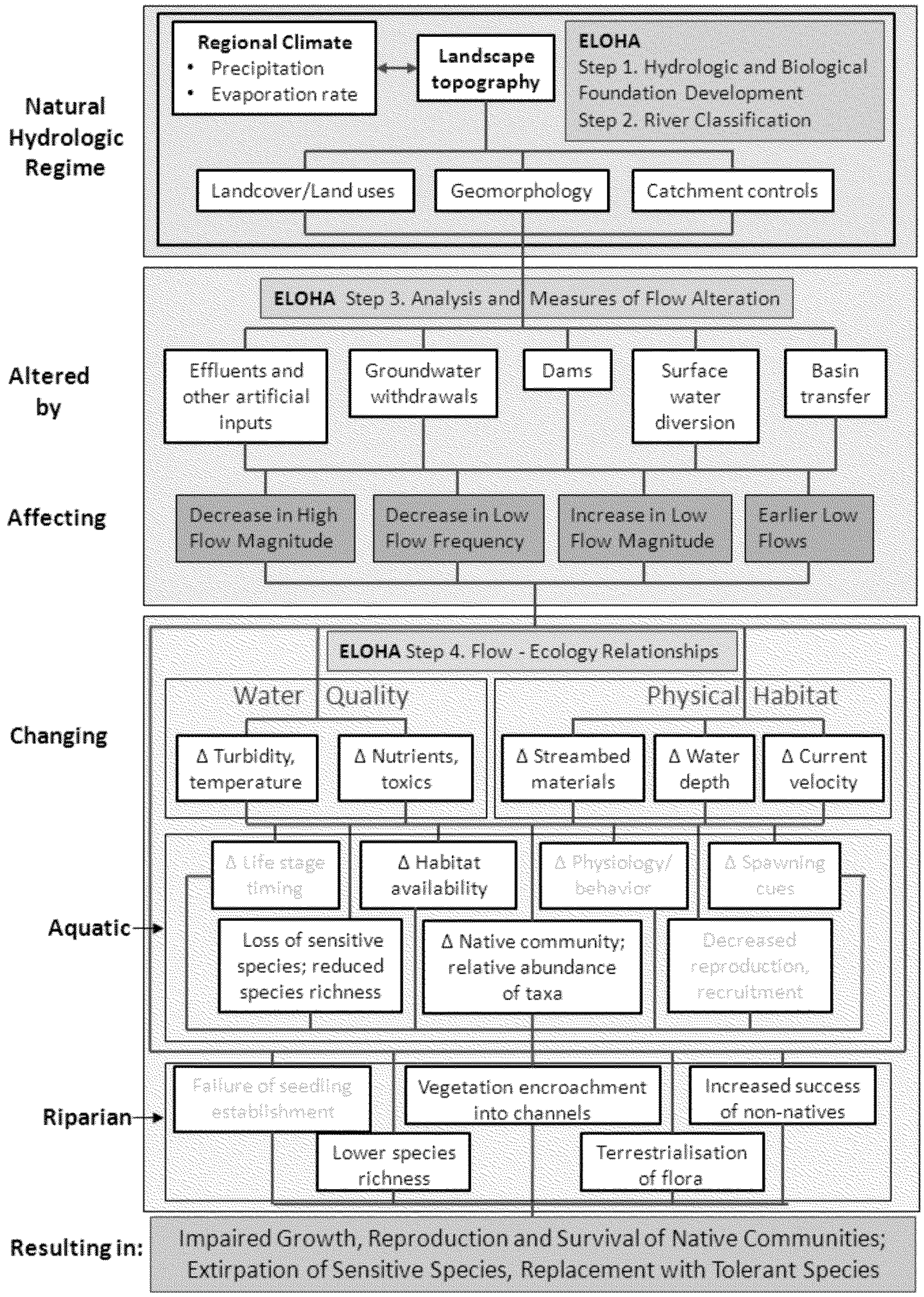
Effects: Alterations from climate change-related impacts affects snowpack timings, amounts, and durations resulting in altered flows. A decrease in winter snow pack affects the timing of winter flooding and the timing of high and low flows. When a snow pack melts early in the season, earlier and lower low flows are observed throughout the watershed. Additionally, a winter that receives a greater proportion of precipitation in the form of rain instead of snow will yield more frequent high flows.

Decreased snow pack results in effects on instream habitat quality primarily through altered flow conditions. These alterations may result in:

- Greater frequency of early winter flooding, disrupting winter spawning or increasing potential for higher mortality or egg mortality of salmon
- Lower flows in summer may encourage juvenile salmon to leave river habitats earlier in the season, resulting in smaller-sized salmon entering the sound causing a greater risk to their survival Timber harvesting impacts the natural hydrologic regime through the increase of sediment loads into the stream tributaries. Logging activities tend to have greater effects on water quality in small tributaries than on water quality of the main stem. Alterations associated with timber harvesting may result in:
    - Increased sediment affects critical life stage timing and organism behavior in salmon and other aquatic life.

12.3 Southwestern United States: New Mexico

Landscape Context:
New Mexico encompasses five Level III Ecoregions: Southern Rockies, Arizona/New Mexico Mountains, Arizona/New Mexico Plateau, Southwestern Tablelalnds, and Chihuahuan Desert. The State spans a large gradient of elevation and precipitation with XX inches in the mountains that reach to over 13,000 ft. to XX inches in the Chihuahuan Desert to an elevation low of just less than 3,000 ft. Streams and rRivers in the State range from high gradient plunge-pool systems to low gradient systems. Most of the State is in a natural setting with areas close to rivers and streams being devoted to agricultural uses.



Stressors:

A study of discharge data from 32 gages across the State Using the Indicators of Hydrologic Alteration software in a study of discharge data from 32 gages across the State it was indicated that the leading observed flow alteration types were consistent with those expected for sites subject to upstream dams, diversions, and groundwater withdrawal:, Decrease in High Flow Magnitude, Decrease in Low Flow Frequency, Increase in Low Flow Magnitude, and Earlier Low Flows were consistent with those expected for sites subject to upstream dams, diversions, and groundwater withdrawal. The dams are primarily used for agricultural purposes and provide large block releases to deliver water to downstream agricultural users. Surface water diversions range from small diversions that only take a fraction of the available water to low dams that stretch across the entire channel to larger diversions that may take all of the available water from the stream/river. Groundwater abstractions are numerous and can range from small wells that supply homes with water to large wells that are used for municipalities and/or center pivot irrigation.

Effects:
These hydrologic alterations may result in changes to the aquatic ecosystem:

- changes in turbidity and temperature, and in concentrations of nutrients and toxics,
- changes in physical habitat such as streambed materials, water depth, and current velocity, as well as others,
- which may result in changes in habitat availability, life stage timing, physiology/behavior, spawning cues, and decreased reproduction and recruitment, leading to loss of sensitive species, reduced species richness and a change in native community and/or relative abundance of taxa;

and changes to the riparian ecosystem:

- vegetation encroachment into channels and failure of seedling establishment which may result in lower species richness, terrestrialisation of flora, and increased success of non-natives which may result in lower species richness, terrestrialisation of flora, and increased success of non-natives.

These changes may eventually lead to impaired growth, reproduction and survival of native aquatic and riparian communities, extirpation of sensitive species, and replacement with tolerant species.

New Mexico has data for those blocks with text in black from various sites throughout the State that could be used to establish flow alteration – ecological response curves (ELOHA Step 4). The blocks with grey text represent more limited datasets from one or a few places in the State, or that could be inferred from the literature as being likely results of these types of hydrologic alterations.

13 Appendix G: A Place-based Example of Fig. 3: Hydrologic processes across a landscape

Figure 2 illustrates most importantly, that downstream segments include cumulative properties of upstream segments, as well as the properties inherent in downstream sections. As examples, we apply these models to four rivers in California that all drain the Sacramento Valley. The east side of the valley is the high, granitic, deeply sculpted Sierra Nevada Mountains. The west side of the valley (and adjacent to the Pacific Ocean), is the lower Coast Range. The Coast Range gets the first inundations of seasonal rainfall, but they are not tall enough to gather a snowpack and in the dry season their watercourses are usually dry, except for the water they receive from small dams and agricultural return flows.

Example 1. (Light green catchment area indicates low impacts.) The McCloud River is fed by springs and snowmelt from Mt Shasta. The valleys are steep-sided and granitic, producing a simple stream network with ground cover of forest in the valleys and barren slopes above. Thus, the **natural hydrologic regime** is characterized by cold and stable flows year round. Forestry has reduced some ground cover and promoted some denser, bushy vegetation. Other impacts have been small. **Changes in flow regime** have been minimal. In 1991 the worst **toxic** spill in American history happened when a railroad car containing 19,000 gallons of metam sodium fell into the river. Most living organisms in the river were killed for 39 miles downstream, to where the toxins were diluted in Shasta Reservoir. The natural flow regime removed the contaminant and the granitic substrate did not retain the toxics so the river biota rapidly re-established.

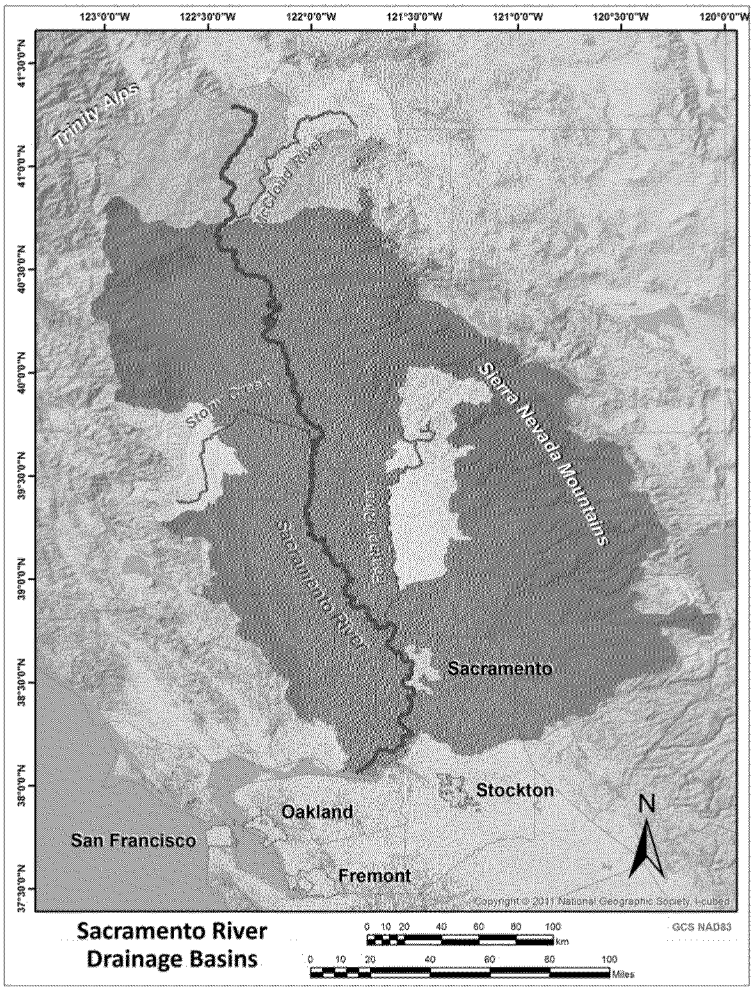
Example 2. (Dark green catchment indicates accumulated upstream impacts.) The Mainstem Sacramento River accumulates flow from the McCloud and several similar steams and captures them behind Shasta Dam in the largest reservoir in the state. Below Shasta Dam the river runs through a very large, flat valley. Thus, the **natural hydrologic regime** is large, clean and cold. As the single largest source of water for the federal Central Valley Project Shasta Reservoir provides irrigation water throughout the valley and is primarily operated for flood control in the winter and spring and for water delivery. **Changes in the flow regime** have generally been lower peaks and higher base flows, decreasing variability across seasons and across years. The reservoir captures sediment and holds a stratified water column so that downstream **temperature** and **sediment loads** are altered and all aspects of **channel habitat** are modified. Most riparian **vegetation** has been removed and the rivers **channelized**. Agriculture and industrial uses are supported by **surface and groundwater diversions,** returned as both **surface runoff** and **discharge.** Land cover is now almost exclusively agriculture and urban development, producing more **impervious surfaces**. Shasta Dam blocks access by Winter-run Chinook salmon to their upstream summer spawning grounds, but cold water releases from the large reservoir pool sustained the population at high levels from 1944 to 1976. The worst California drought on record occurred in 1976-77. The reservoir was drained to supply agricultural needs, leaving no cold water for discharge in 1977 and the population crashed. Demands for **water surface delivery** and for **inter-basin transfer** to the San Joaquin Valley now make flow, substrate and temperature conditions below the dam a crucial management focus as they **impair the reproduction** of salmon.

Example 3. (Light green catchment area indicates low impacts.) Stony Creek, is tributary to the mainstem Sacramento River and flows off the Coast Range on the west side of the Valley. Flow is supplied by rainfall in winter months, snowfall is rare and seldom long-lasting. **Physiography** is gentle hills of sedimentary rock covered by scattered oak woodland and chaparral, producing a rather complex **stream network** in a fairly small watershed. The **natural hydrologic regime** is largely intermittent streams, with sudden high flows during times of winter rainfall. The upper watershed lies within the Mendocino National Forest, so vegetation is largely unchanged, but is now agriculture in the valley floor. The main **alteration to flow** comes from two dams that capture winter runoff to deliver to agriculture in summer and fall, thus producing constant flow in channels that were historically intermittent. The constant flows allow invasion of formerly isolated pools by invasive species that **compete and prey** upon native stream fishes.

Example 4. (Light green indicates low impacts.) The Feather River drains 16000 sq km of the southern Cascade and Sierra Nevada mountain ranges that receive large amounts of precipitation, mostly as snow. The **physiography** supports exceptionally complex **stream network structures**. The native vegetation included large areas of forest and meadow. The **natural flow regime** was high, sustained, coldwater flows for much of the year.

Many **dams**, including several large ones, reduce peak flows and augment summer and drought flows. Water **temperatures** in the lower reaches are elevated. **Vegetation cover** has shifted to agriculture. The watershed was a gold **mining** center in the nineteenth century and suffered massive soil loss that filled downstream channels with sediments **contaminated** by mercury. Downstream movements of sediments altered **substrate texture** and **channel habitat.** Small dams were built in the late 1800s to slow the downstream movement of contaminated sediments and these are still a source of mercury and sediment contamination today. Sediment and temperature changes **impair the reproductive success** of salmon.

Example 5. (Dark green catchment indicates accumulated upstream impacts.) The Sacramento-San Joaquin Delta combines water from both the Sacramento River from the north and the San Joaquin River from the south in a large inverted delta; that is, the delta narrows as it approaches San Francisco Bay and the ocean. Together the watersheds of the two rivers are called the Central Valley, the floor of which is one of the largest flat areas in the world. This flat **physiography** supported a vast inland sea during wet times and a prodigious wetland expanse the rest of the time. Agricultural development led to an almost total **loss of native vegetation. Dams** on all major tributaries reduced flooding and seasonal and interannual variability in flows, as well as reducing **sediment** loads downstream and reducing **turbidity**. **Interbasin transfers** from upstream tributaries reduce inflows to the delta, particularly from the San Joaquin River. Agriculture and urban development alter substantial surface runoff and contributes hundreds of different **toxic** chemicals and **nutrients**. **Channelization** has eliminated most connectivity between local land and the water channels, except for. **Channelization** has increased depth and greatly reduced **Depth, width, & sinuosity.** Increased depth has resulted in localized **low dissolved oxygen** concentrations. Within the delta, substantial **inter-basin water transfers** combine with upstream transfers to greatly reduce outflows to San Francisco Bay except at times of floods. These reduced flows result in substantial increases in **salinity.** Overall, these multiple changes to the chemical and physical aquatic environment of the delta interfere with **reproductive success and timing, food availability, physiology and behavior and give a competitive advantage to introduced species, including predators.**



Sacramento River Drainage Basins